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Prescott et al.

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(45) **Date of Patent: Jul. 14, 2015**

(54) **VALVE ASSEMBLY**

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Mar. 27, 2012 (GB) 1205382.3

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F15B 13/02 (2006.01)
F16K 11/07 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F16K 11/07*** (2013.01); ***B60T 8/327*** (2013.01); ***B60T 13/662*** (2013.01); ***B60T 13/683*** (2013.01); ***B60T 15/025*** (2013.01); ***B60T 15/027*** (2013.01); ***F16K 15/186*** (2013.01)

(58) **Field of Classification Search**
CPC F16K 11/07; F16K 15/186; B60T 8/327; B60T 13/662; B60T 13/683; B60T 15/027; B60T 15/025
USPC 137/596, 596.1, 596.18, 596.2, 627.5, 137/625.66
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,754,840 A * 7/1956 Hicks, Jr. 137/454.6
3,977,734 A * 8/1976 Ronnhult et al. 303/119.3
(Continued)

FOREIGN PATENT DOCUMENTS

DE 44 15 925 12/1994
EP 0 140 862 5/1985
(Continued)

OTHER PUBLICATIONS

Search Report dated Jul. 17, 2012, United Kingdom Patent Application No. GB1205382.3.
(Continued)

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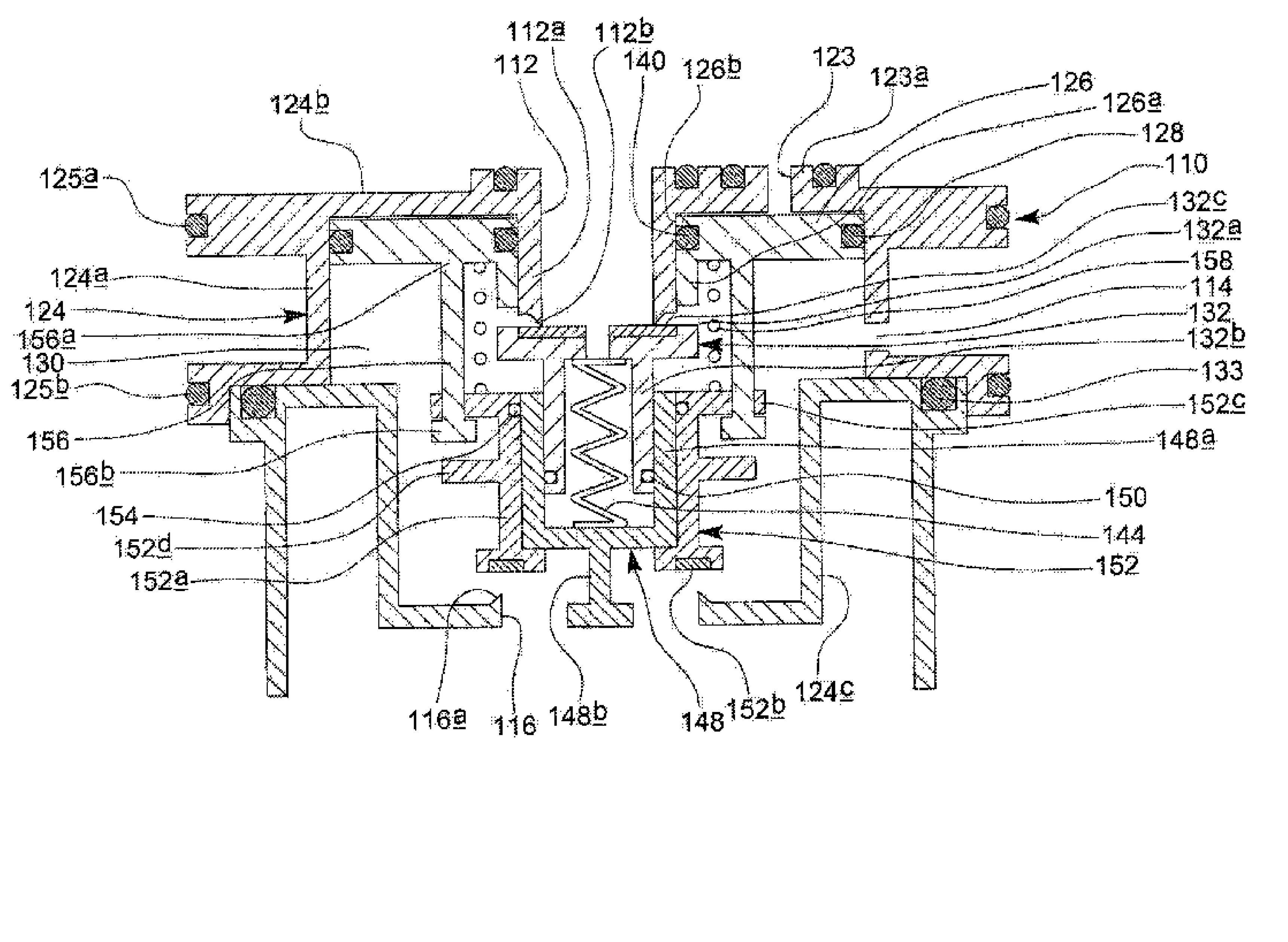
(57) **ABSTRACT**

A valve assembly comprising an inner housing in which is provided a first port, a second port, and a third port, and a valve member assembly which is movable between a first position, a second position, and a third position. An outer housing is separate from and encloses at least part of the inner housing, the outer housing having a first port and a second port, the Inner housing and outer housing each being provided with first mating parts, which engage to provide a substantially fluid tight seal while enclosing a conduit for fluid communication between the first port of the inner housing and the first port of the outer housing, and second mating parts, which engage to provide a substantially fluid tight seal while enclosing a conduit for fluid communication between the second port of the Inner housing and the second port of the outer housing.

17 Claims, 17 Drawing Sheets



(51) **Int. Cl.**

B60T 8/32	(2006.01)
B60T 13/66	(2006.01)
B60T 13/68	(2006.01)
B60T 15/02	(2006.01)
F16K 15/18	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,037,879	A *	7/1977	Horowitz	303/22.2
4,466,672	A *	8/1984	Maddrick	303/22.1
4,499,921	A *	2/1985	Stoll	137/627.5
4,627,668	A *	12/1986	Camm	303/40
5,897,174	A *	4/1999	Ehrlich	303/40
5,906,351	A *	5/1999	Aardema et al.	251/30.01
5,947,239	A *	9/1999	Koelzer	188/352
6,238,013	B1 *	5/2001	Koelzer	303/118.1
7,147,006	B2 *	12/2006	Shaw et al.	137/627.5
7,229,063	B2 *	6/2007	Hameister et al.	251/129.15
7,389,795	B2 *	6/2008	Potter et al.	137/625.64
7,438,276	B2 *	10/2008	Yoshikawa et al.	251/129.08
7,647,942	B2 *	1/2010	Weston	137/503
8,231,818	B2 *	7/2012	Bamber	264/273
2002/0069920	A1 *	6/2002	Reinelt et al.	137/625.66
2002/0124891	A1 *	9/2002	Frank et al.	137/596
2004/0035478	A1 *	2/2004	Herbst et al.	137/627.5
2005/0087243	A1 *	4/2005	Shaw et al.	137/625.64
2006/0099090	A1	5/2006	Kramp et al.	
2007/0186985	A1 *	8/2007	Potter et al.	137/596.16
2010/0199844	A1 *	8/2010	Hilberer	96/118
2011/0042604	A1 *	2/2011	Jens	251/324
2011/0297494	A1 *	12/2011	Shaw et al.	188/152
2012/0031717	A1 *	2/2012	Prescott et al.	188/151 R
2012/0145252	A1 *	6/2012	Hunnicutt	137/14
2013/0263953	A1 *	10/2013	Prescott et al.	137/625.42

FOREIGN PATENT DOCUMENTS

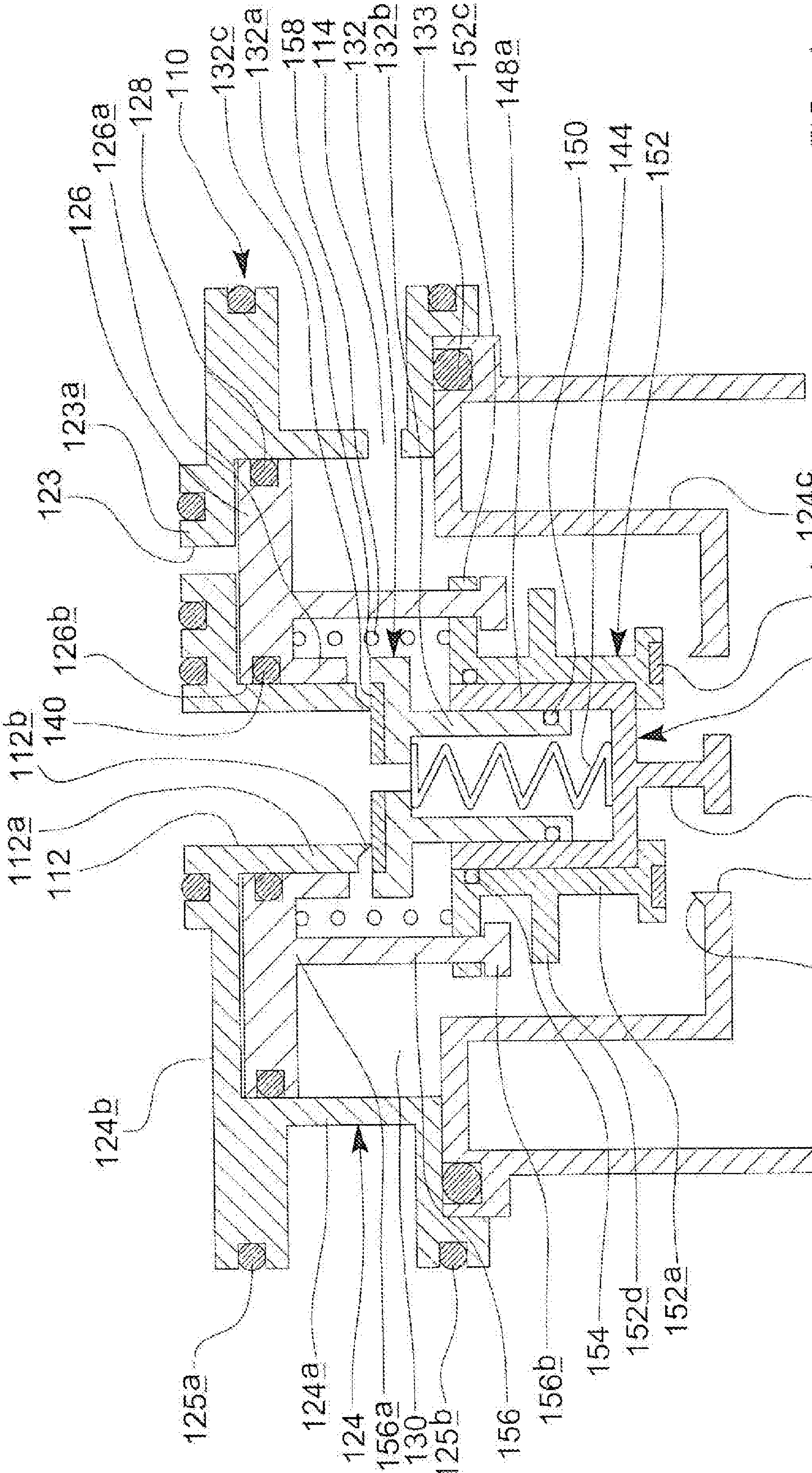
EP	0 274 781	7/1988
EP	2 311 672	4/2011
GB	2 407 131	4/2005
GB	2467957	8/2010
WO	2011151645	12/2011

OTHER PUBLICATIONS

Search Report dated May 2, 2012, United Kingdom Patent Application No. GB1122011.8.

International Search Report dated Mar. 8, 2013, International Application No. PCT/GB2012/053137.

* cited by examiner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152b
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126b
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125b
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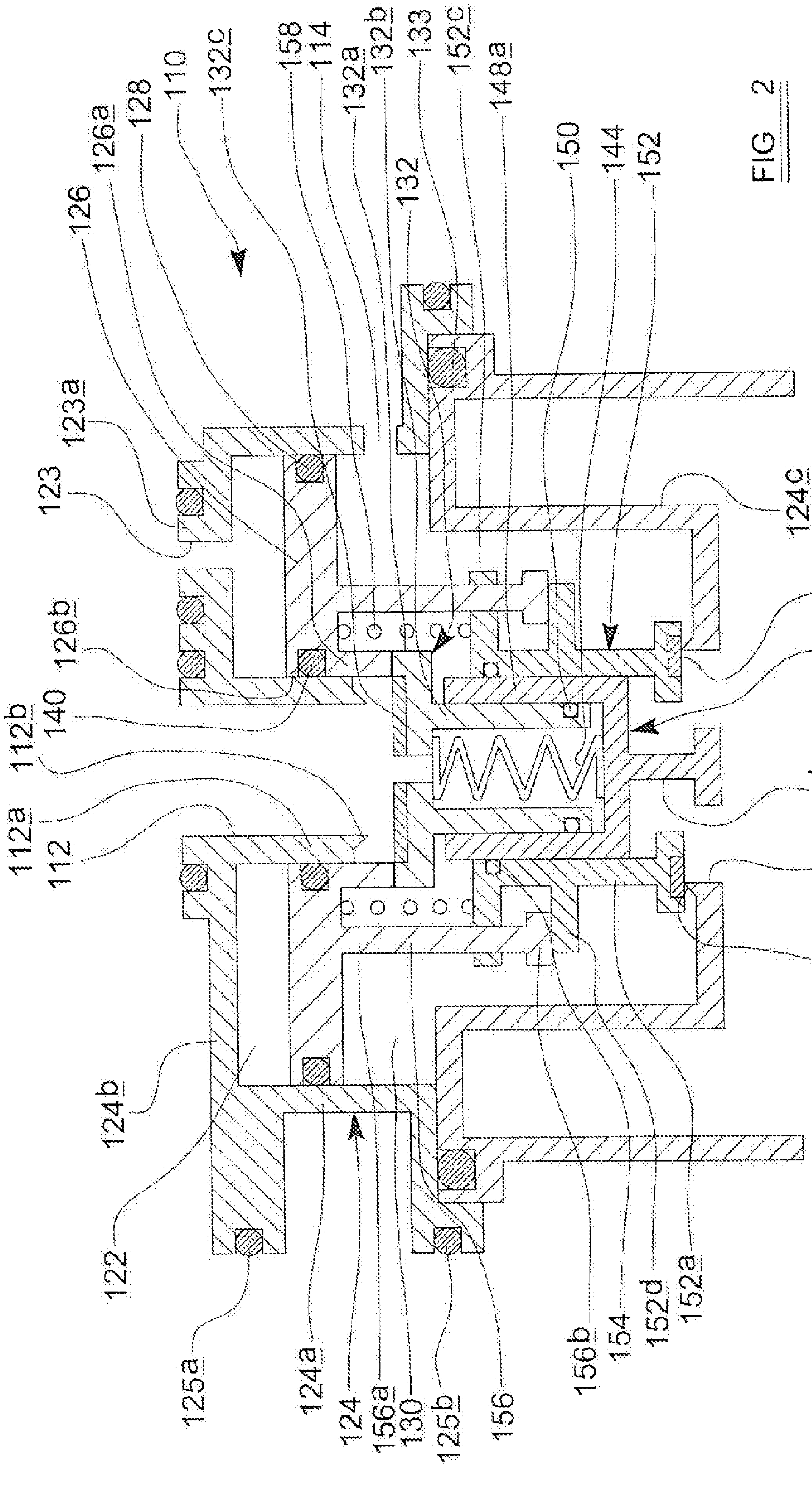
156b
154
152d
152a

FIG 1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112a
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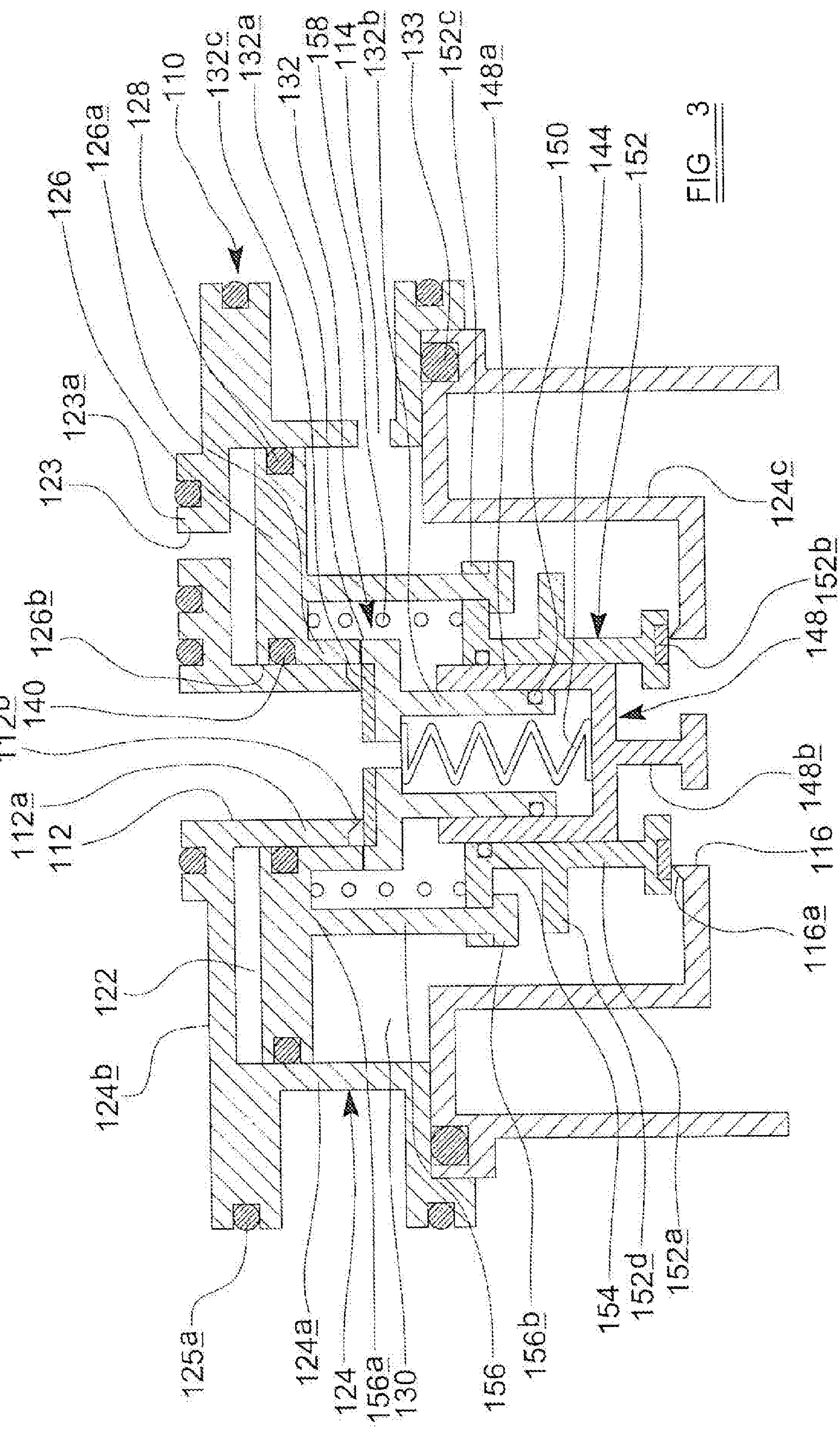
152a

FIG 2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122
124b
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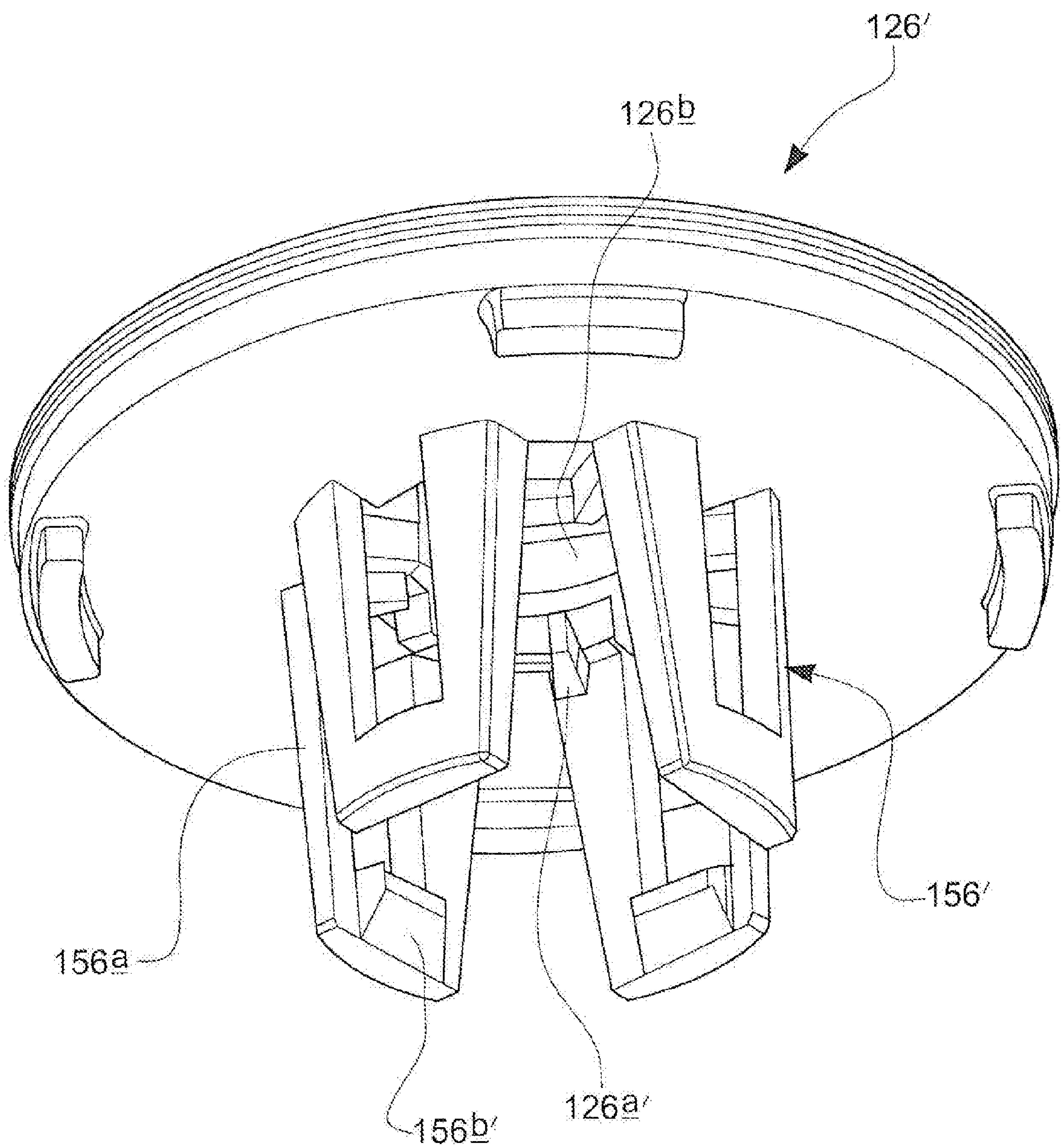
152d
152a

FIG 3



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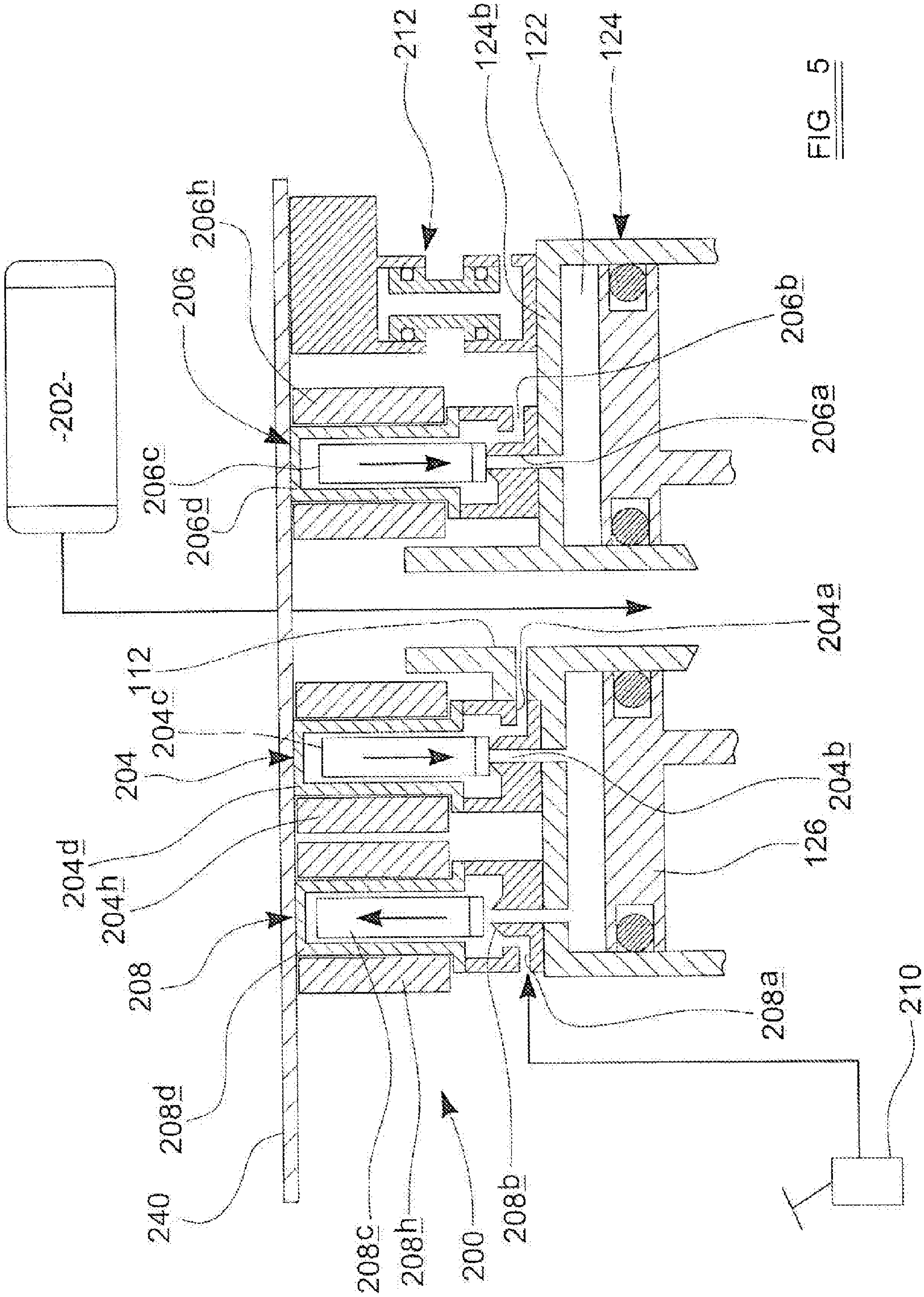

-202-
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FIG 5

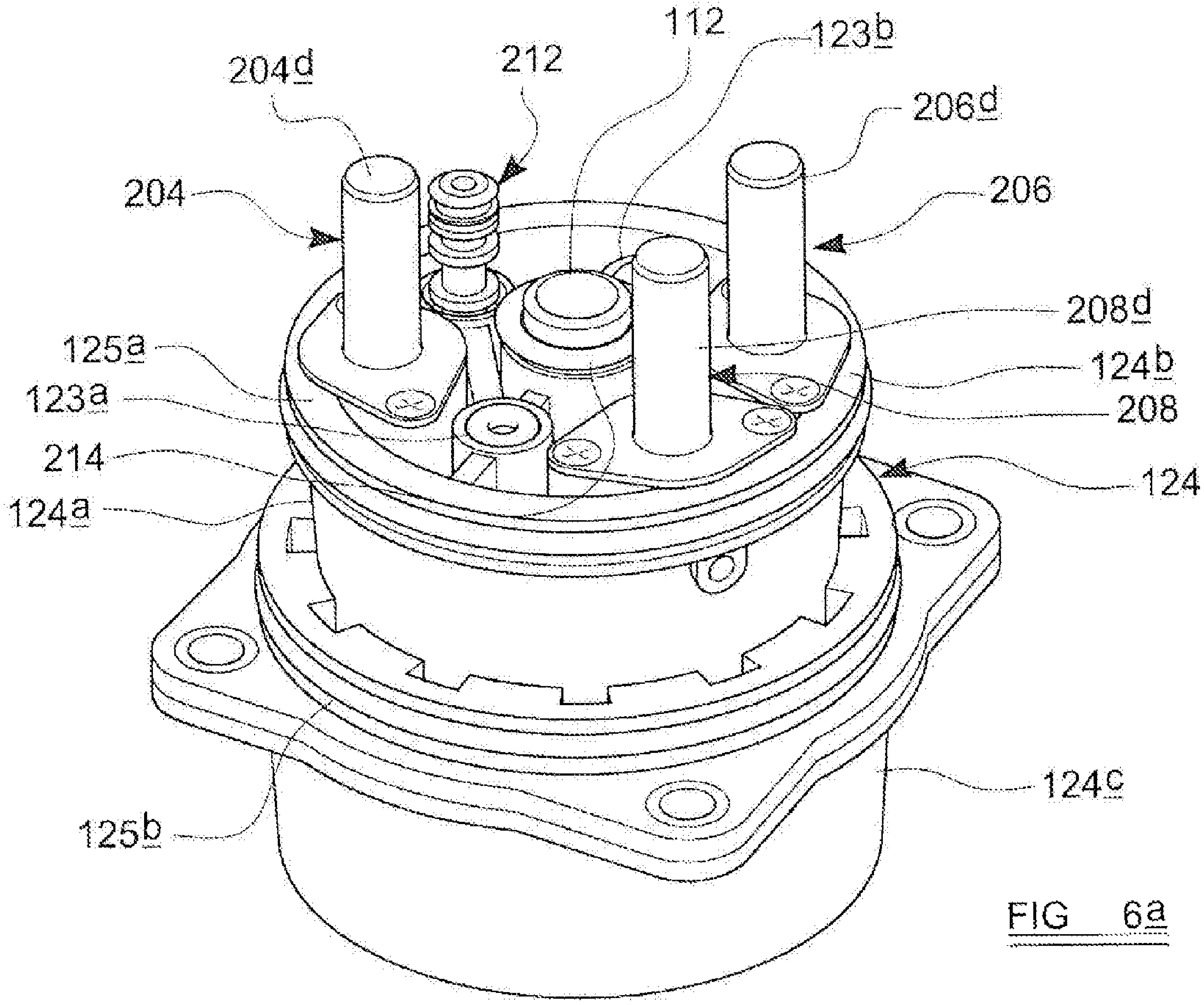
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FIG 6a

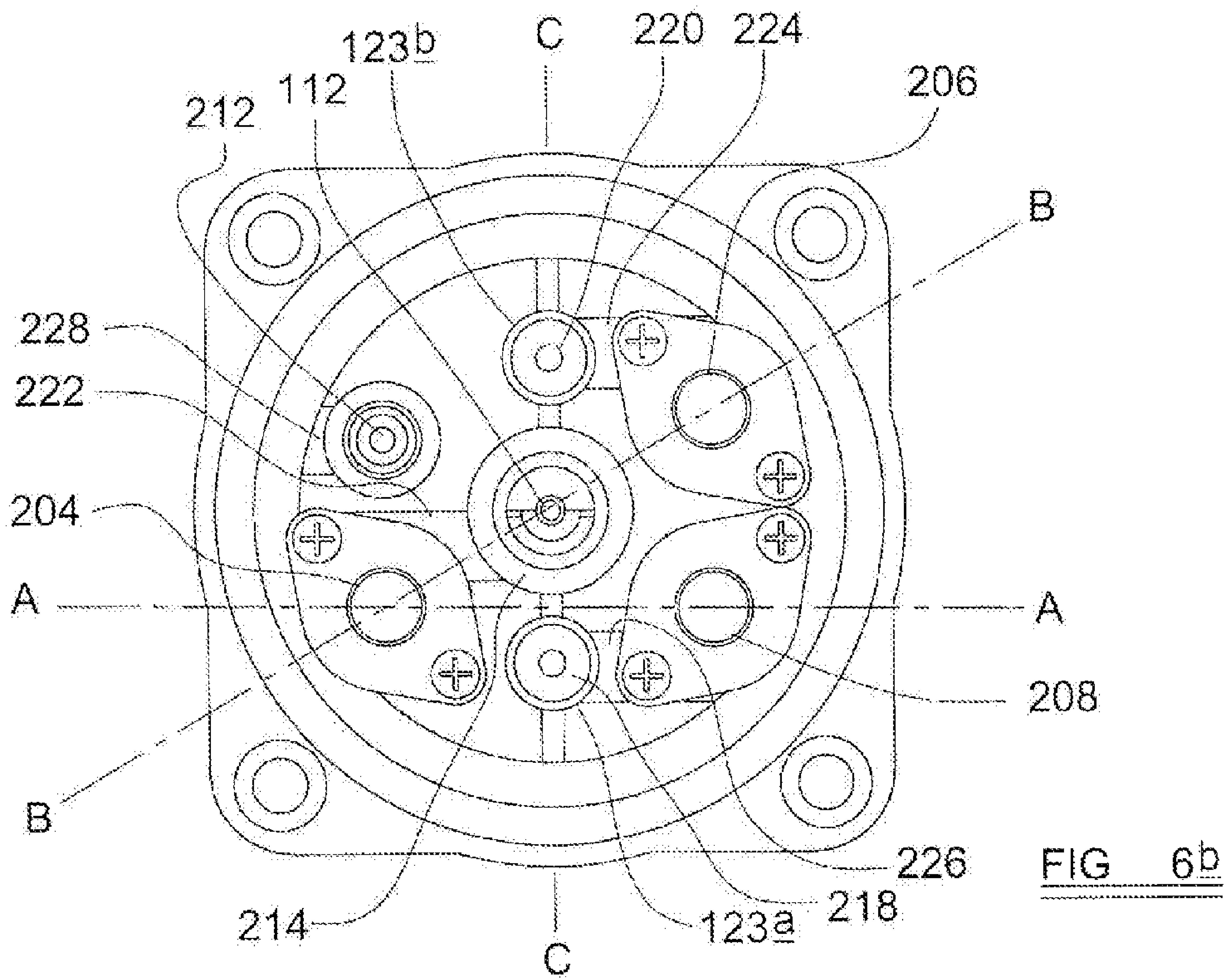
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FIG 6b

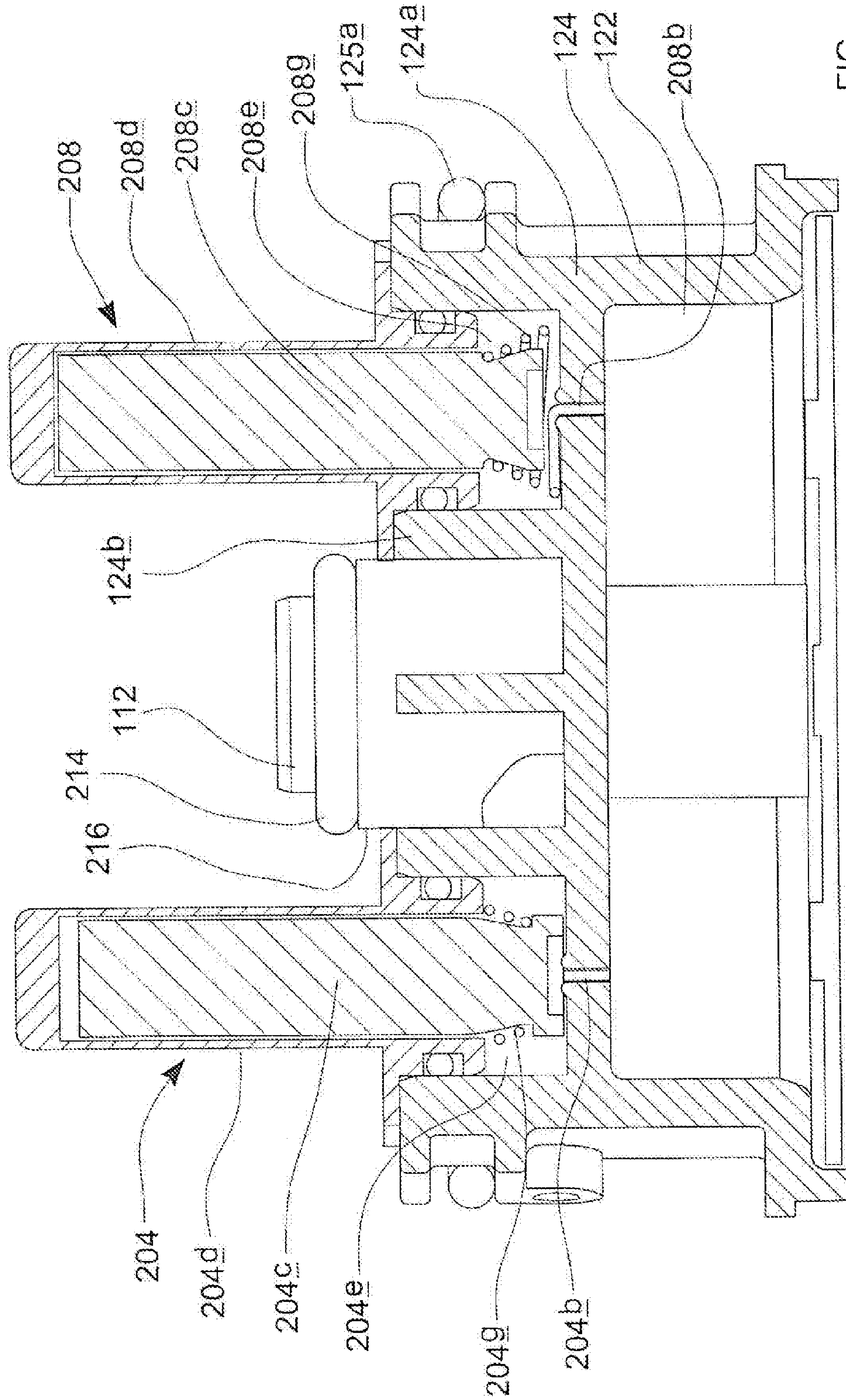
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FIG 6c

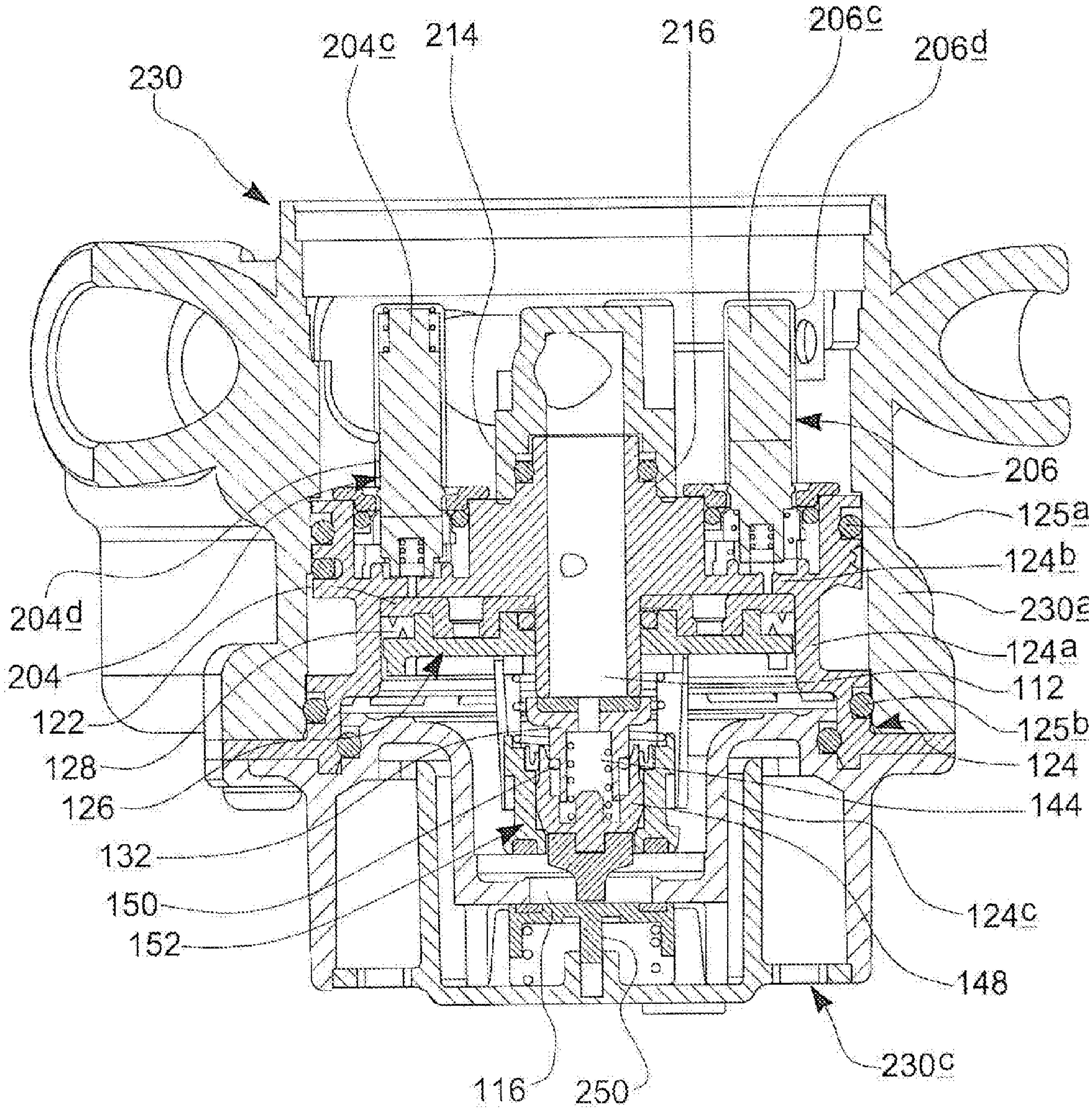
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FIG 6d

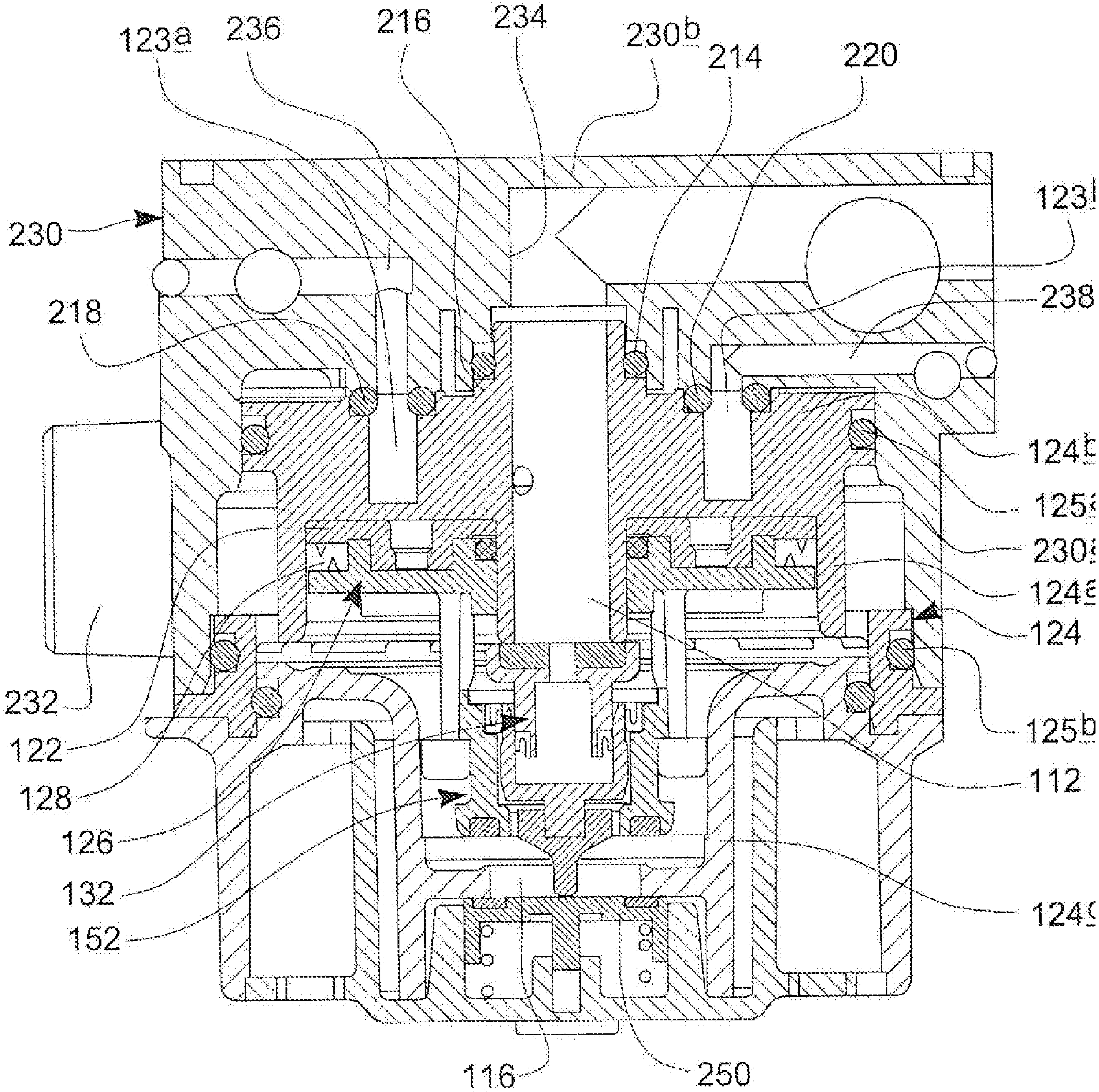

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FIG 6e

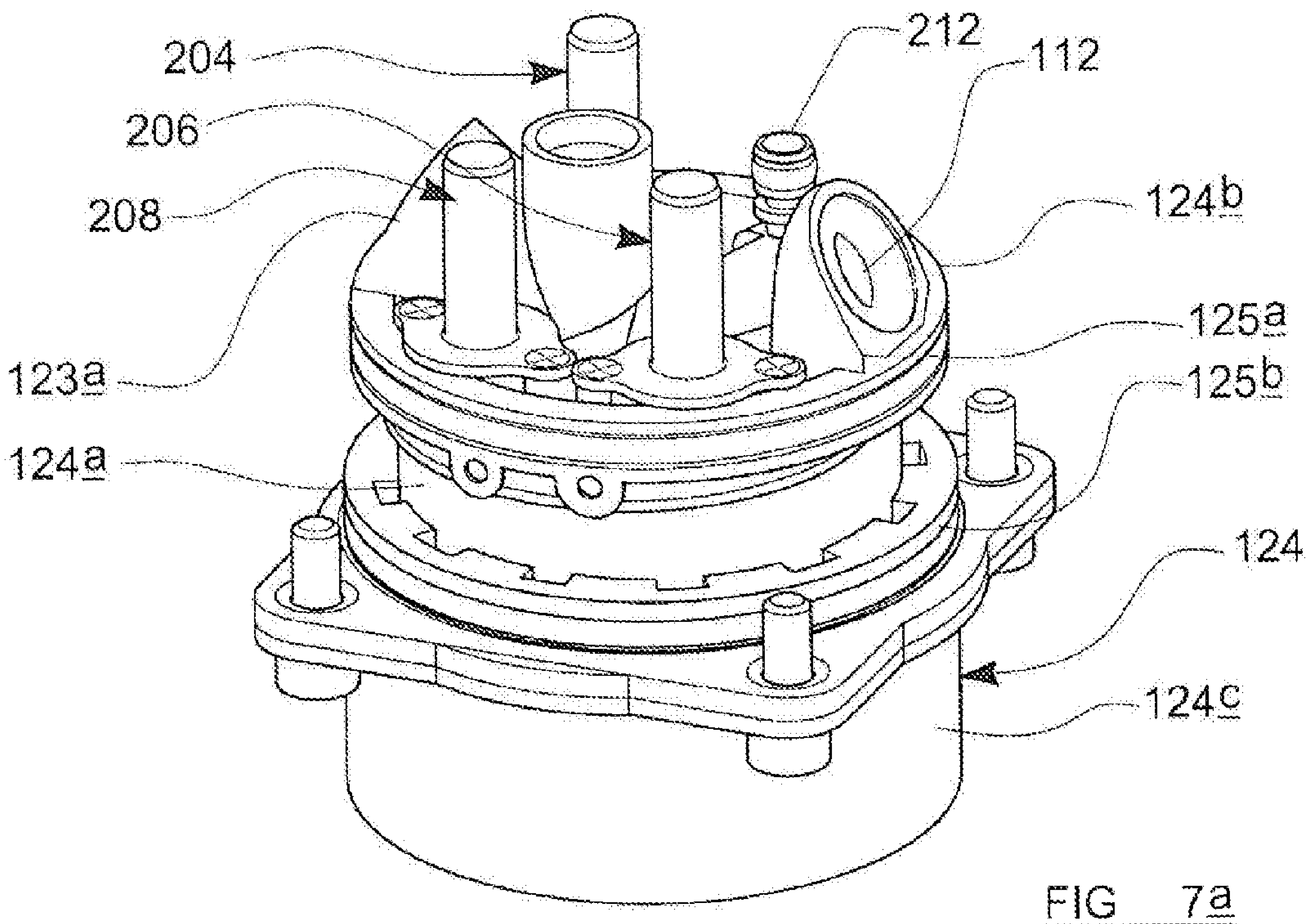
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FIG 7a

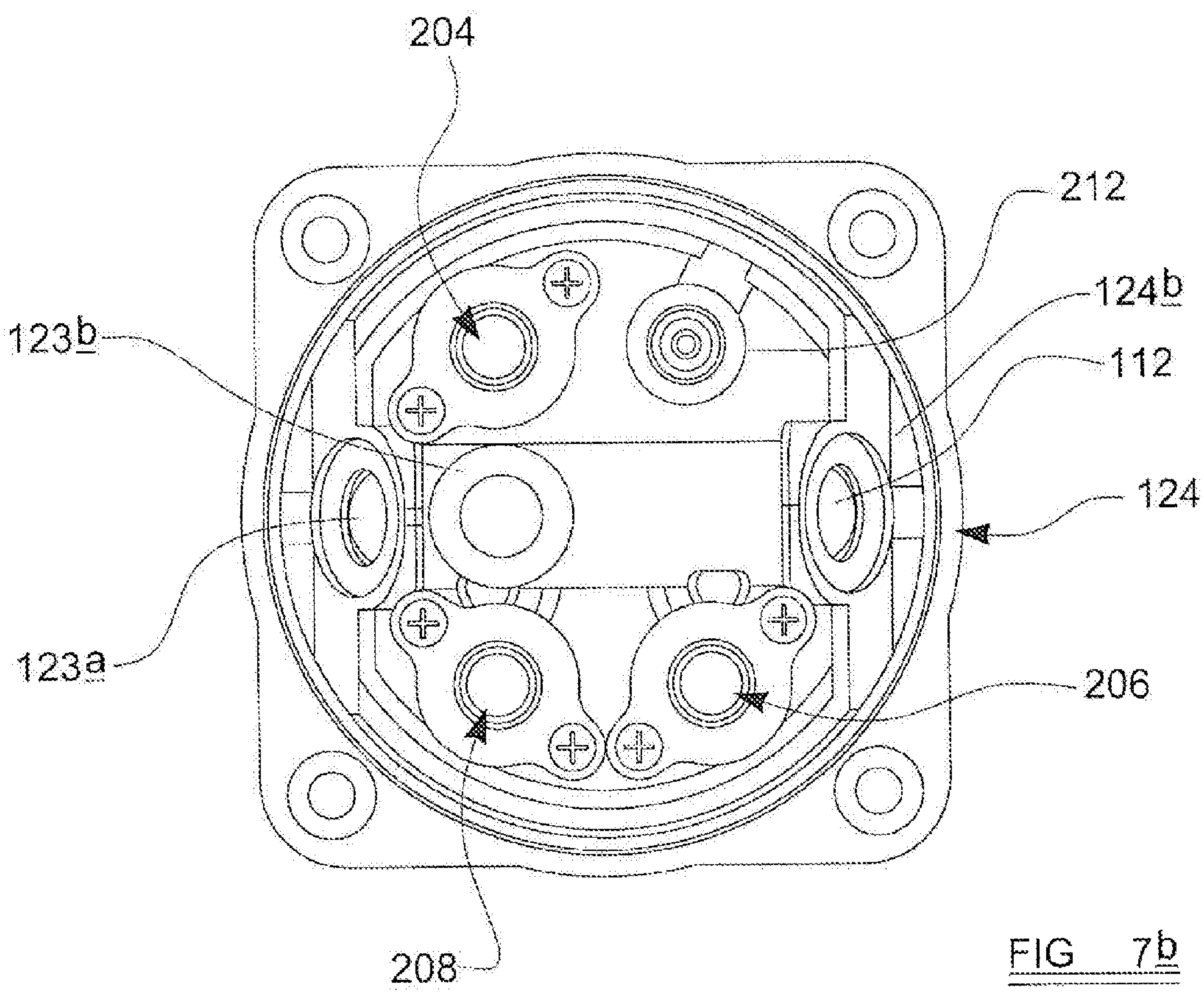
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FIG 7b

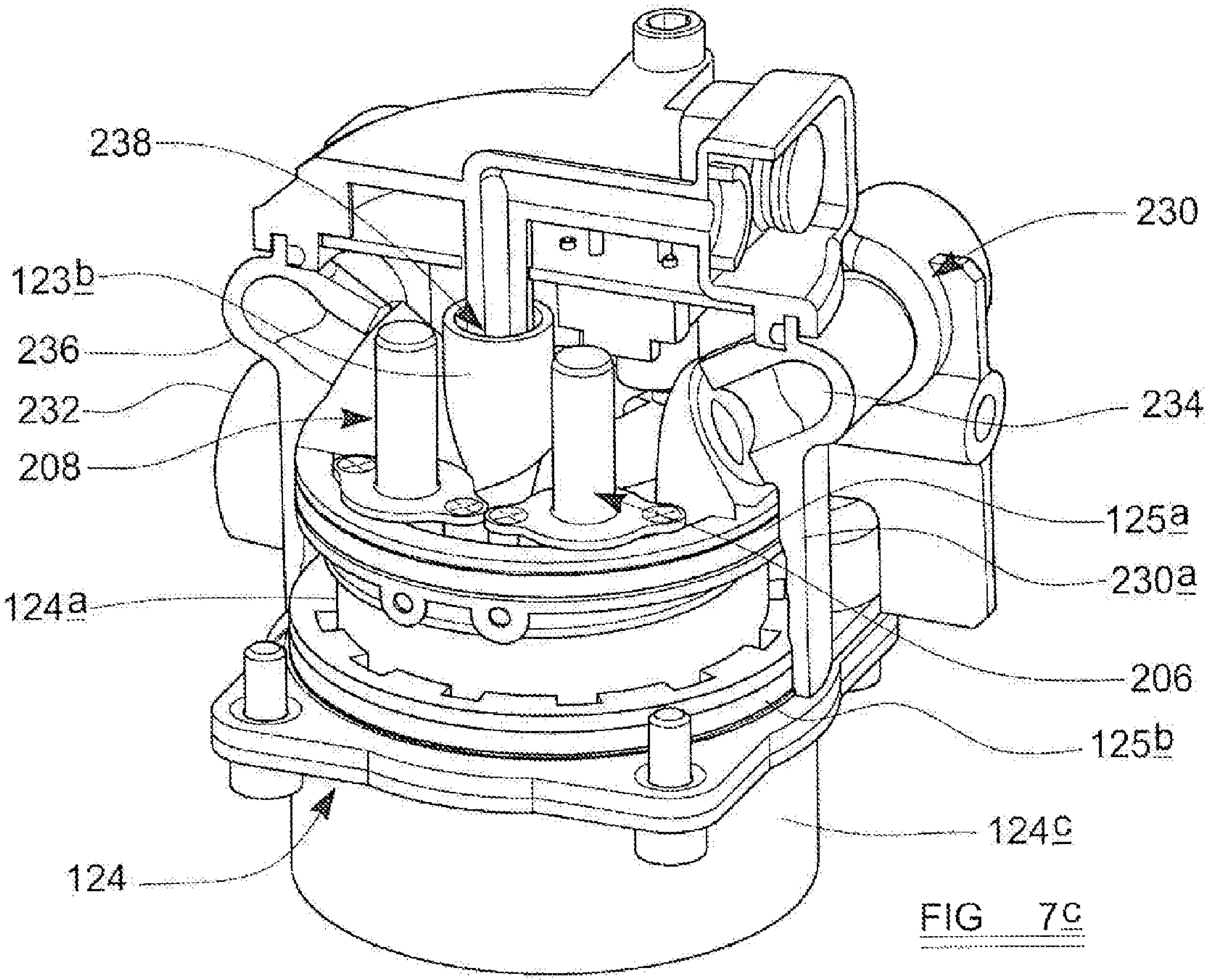
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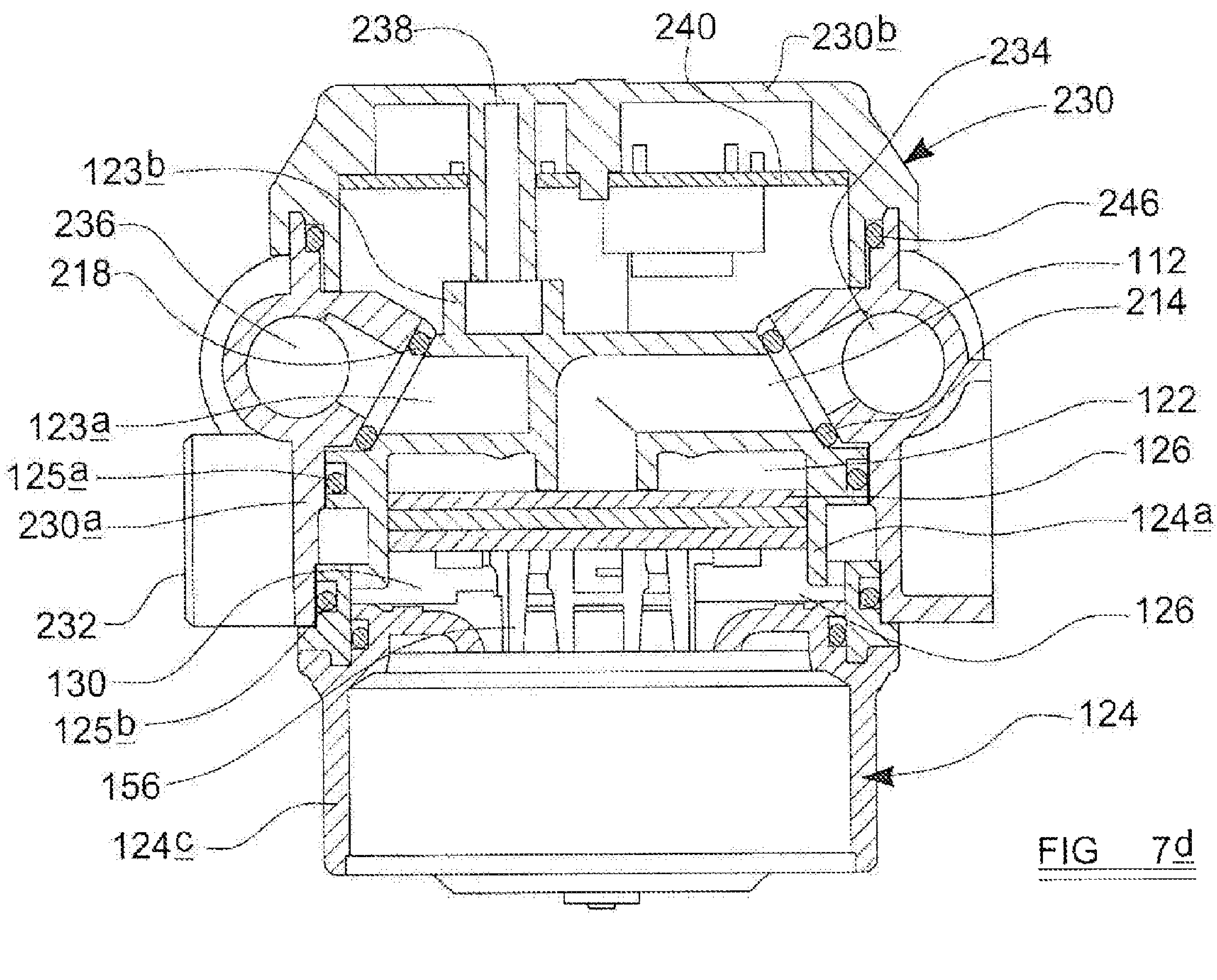
FIG 7c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124c

FIG 7d

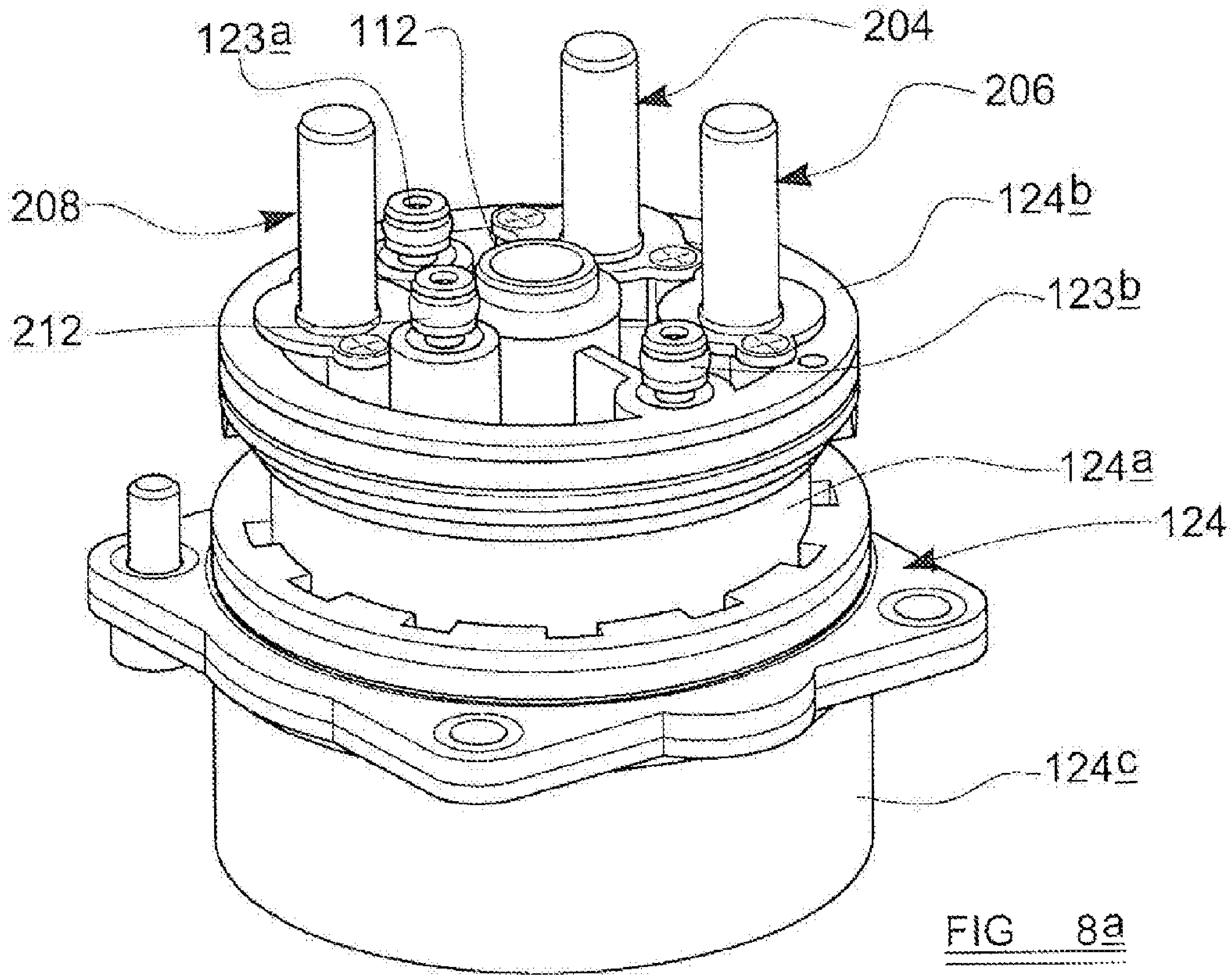
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FIG 8a

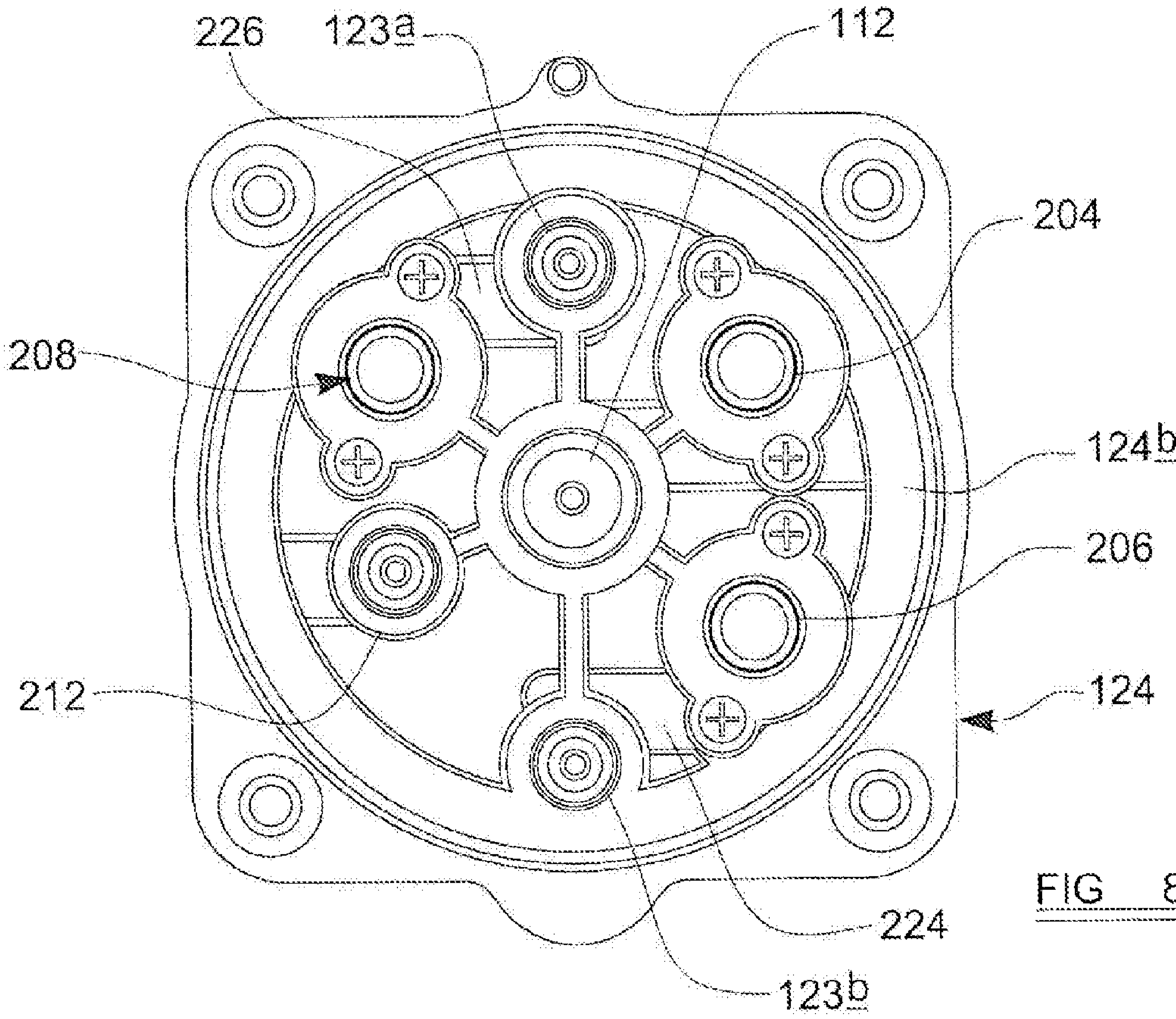
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FIG 8b

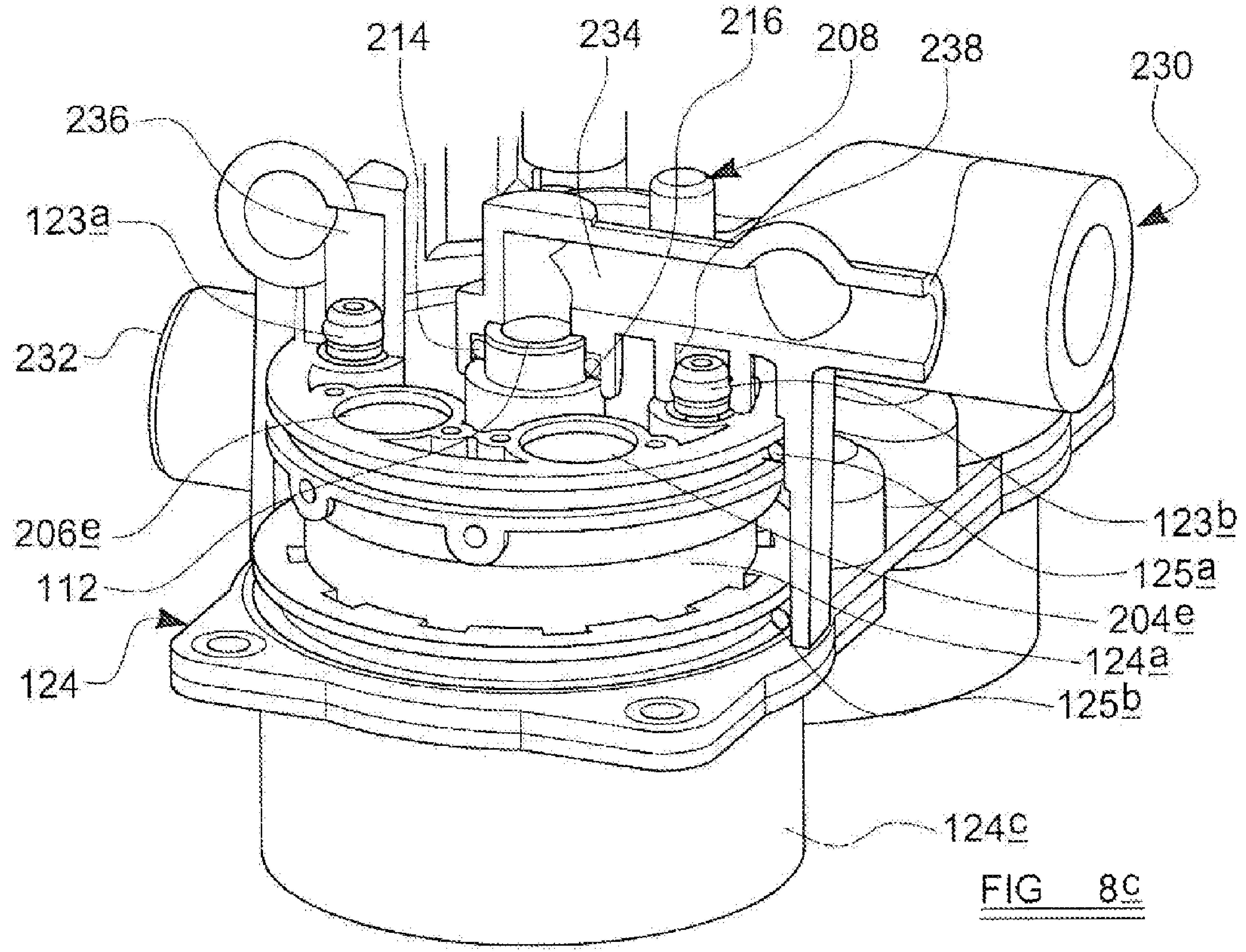
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FIG 8c

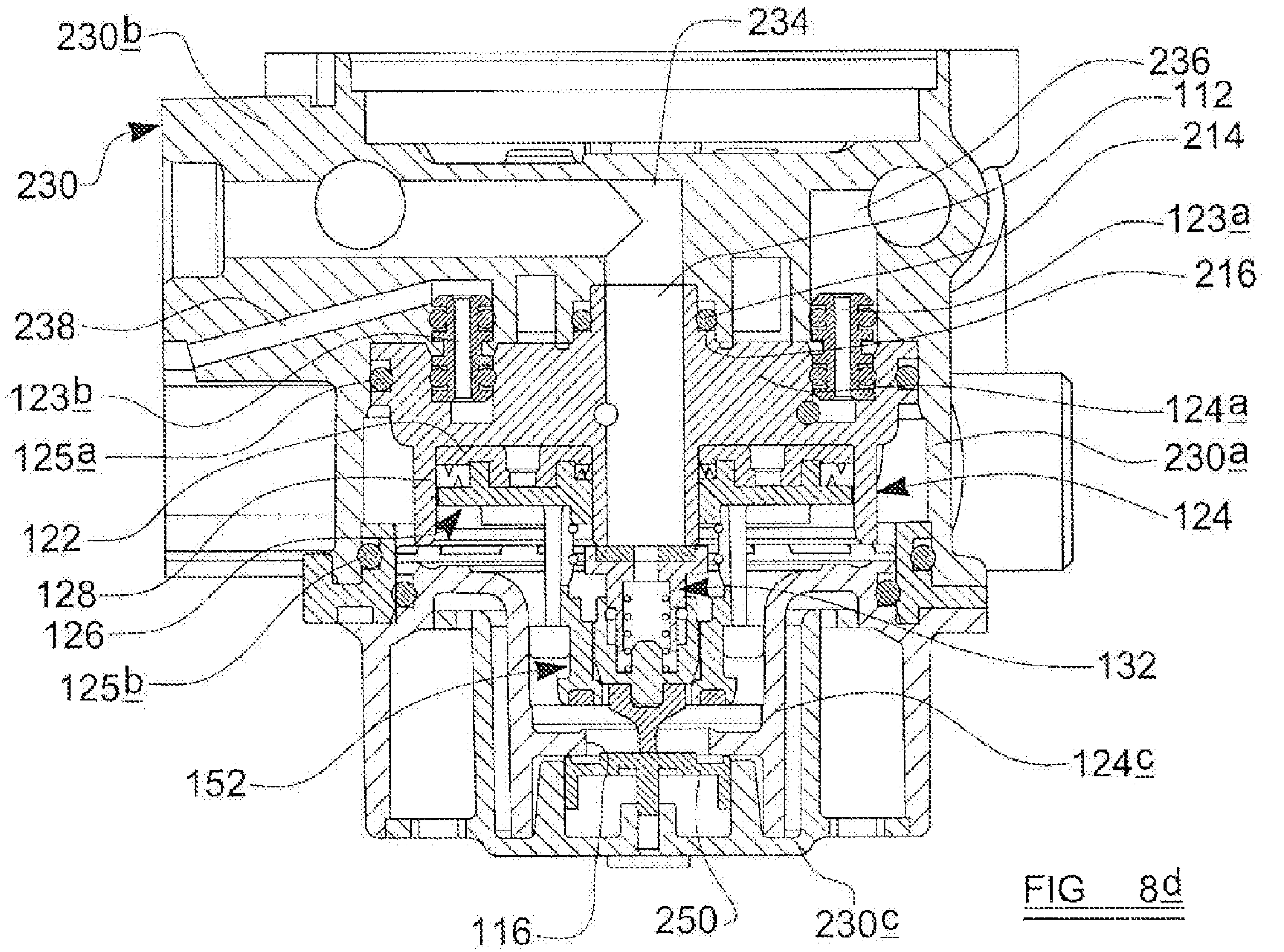
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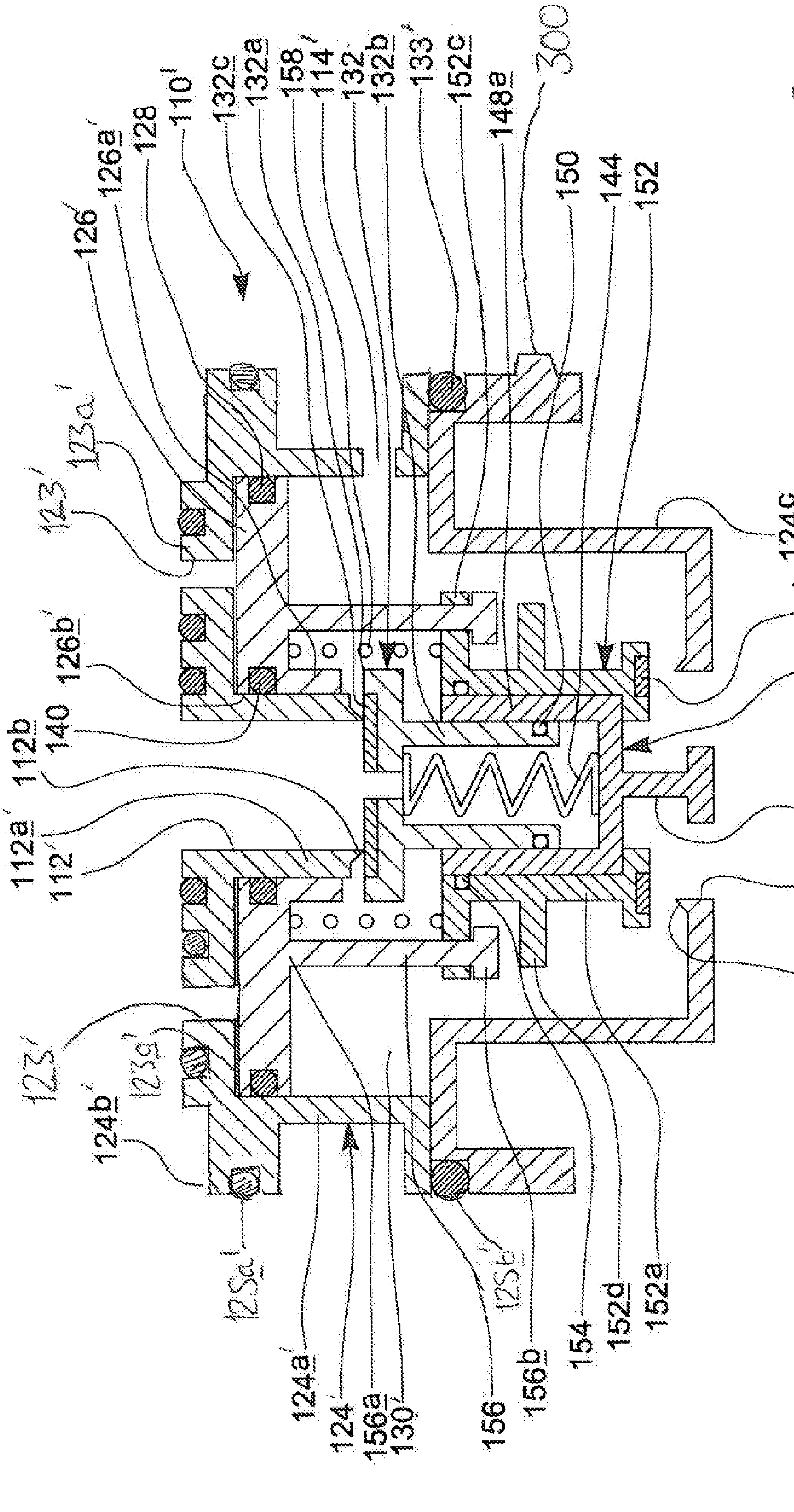
FIG 8d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123'
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FIG 9

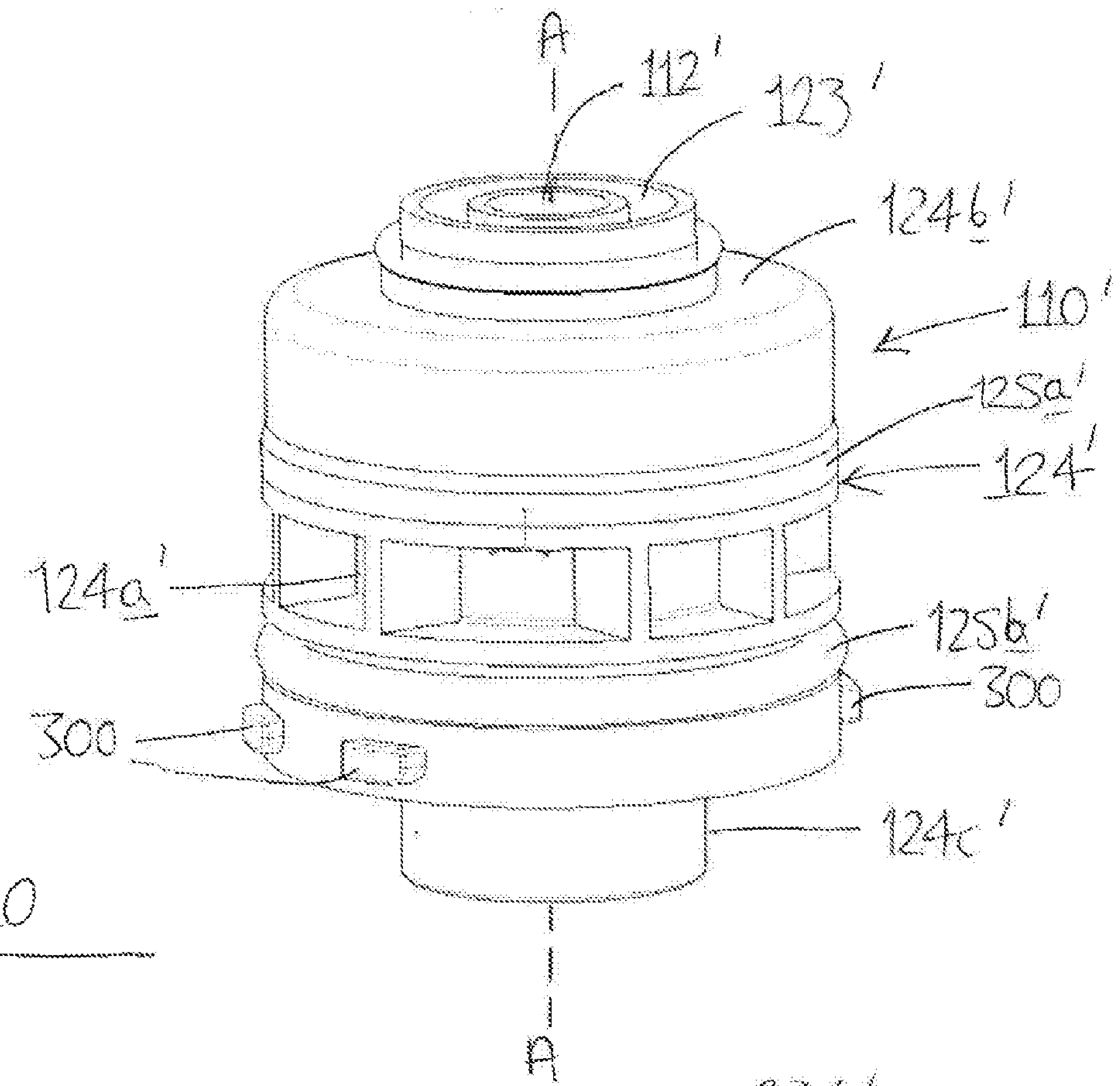

Figure 10

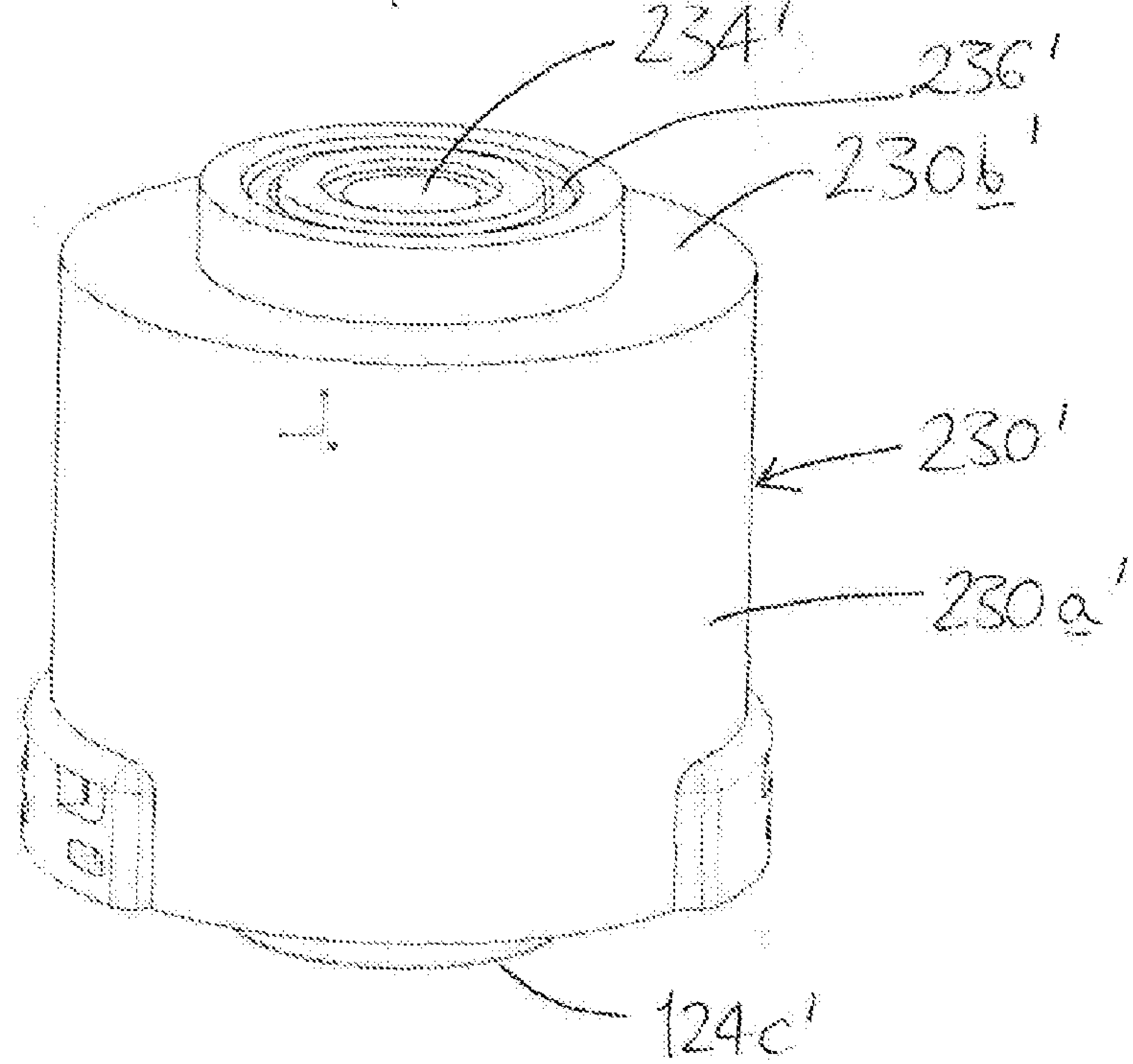

Figure 11a

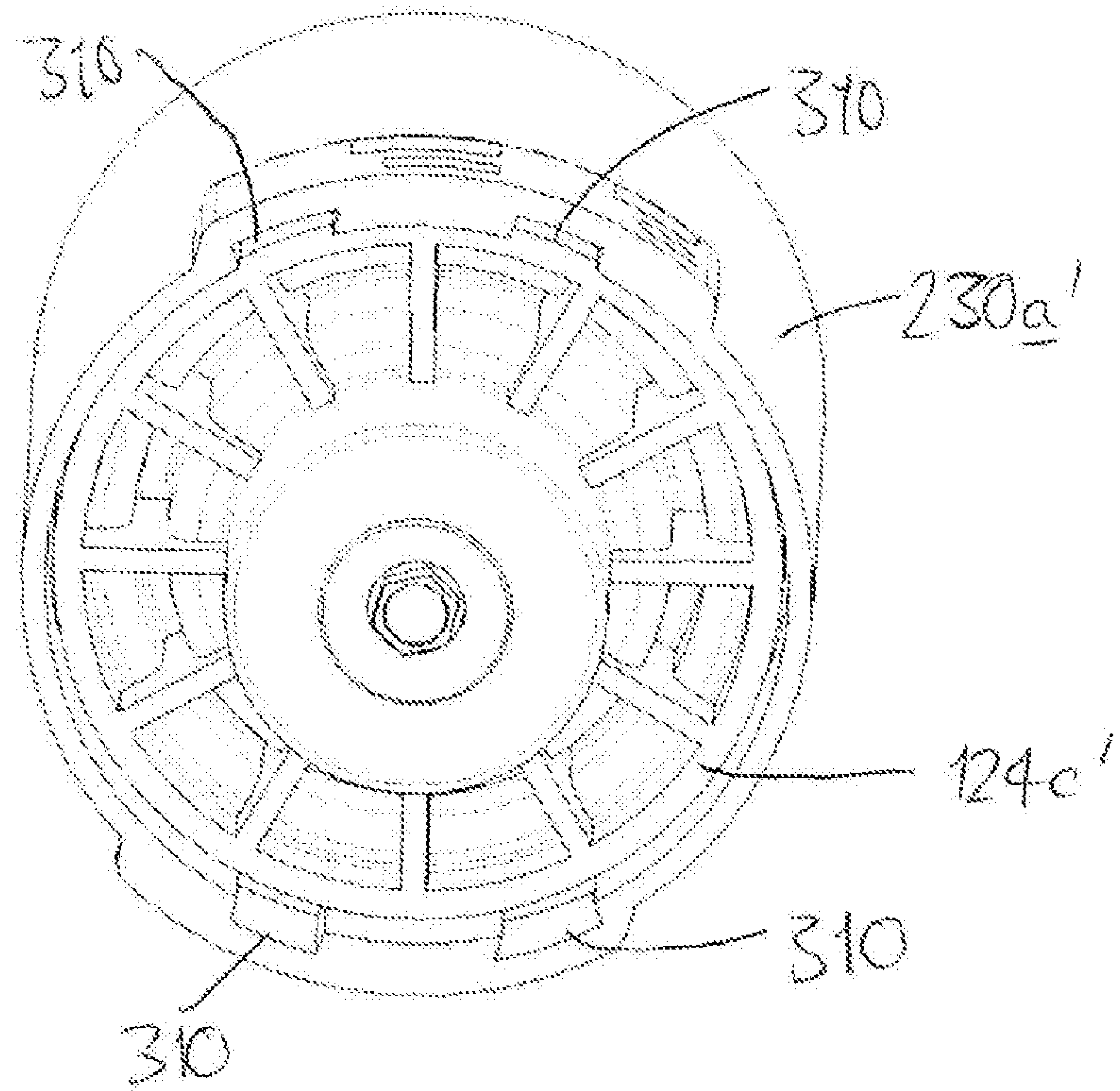

Figure 11b

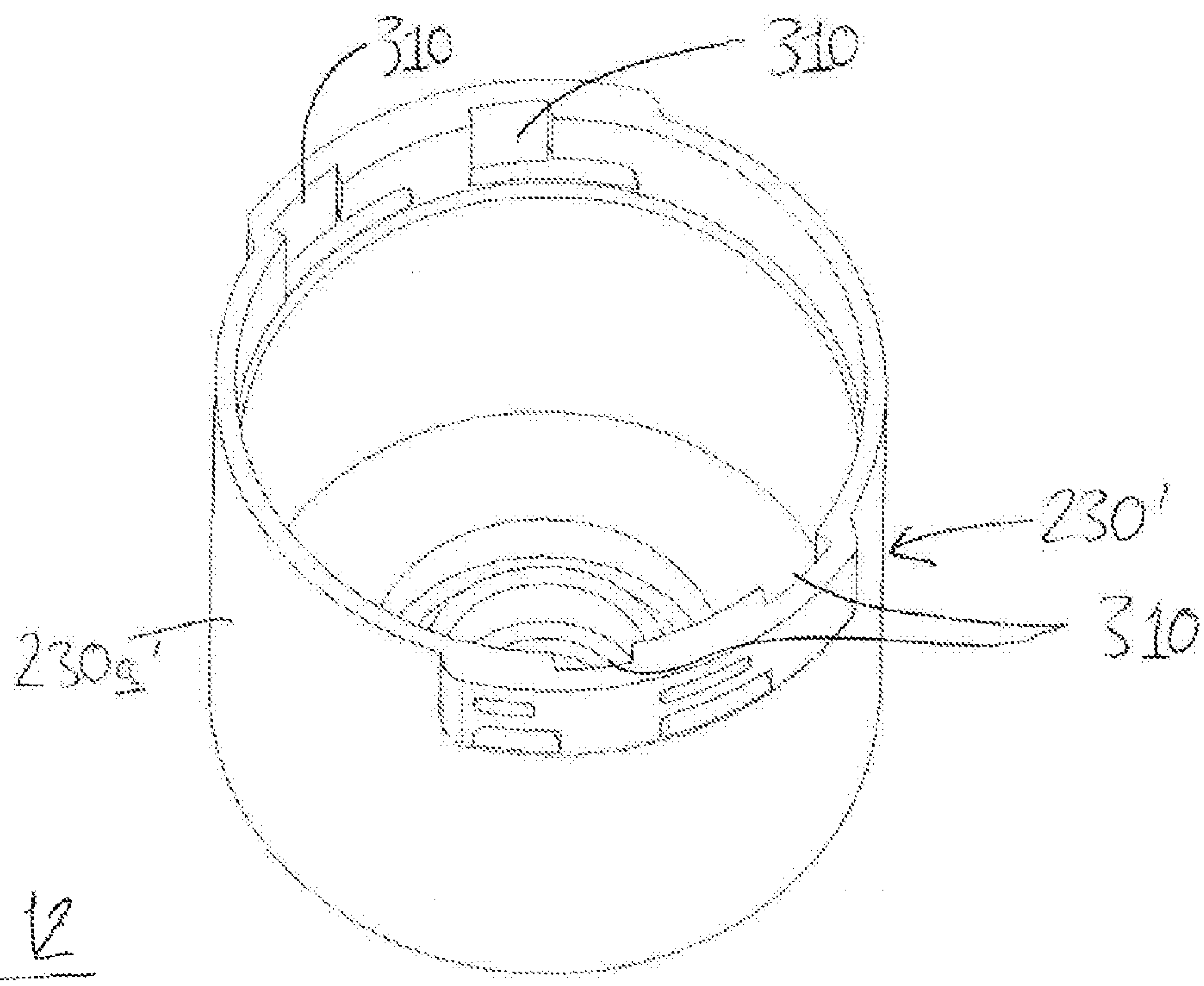

Figure 12

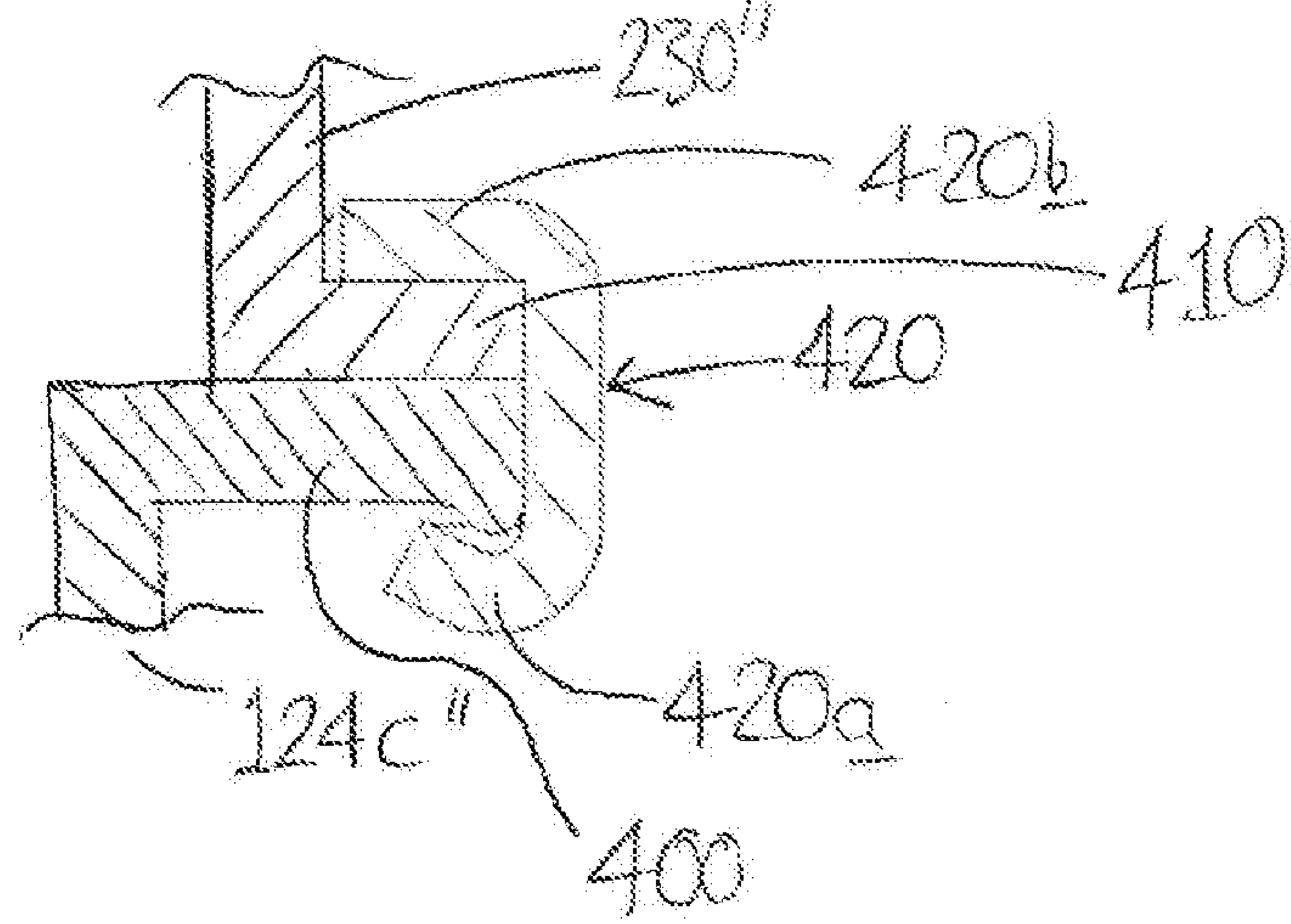

Figure 13

VALVE ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the national stage application of, and claims priority to, International Application No. PCT/GB2012/053137 filed Dec. 14, 2012, which was published in the English language on Jun. 27, 2013 as International Publication No. WO 2013/093433. International Application No. PCT/GB2012/053137 claims the benefit of United Kingdom Patent Application No. 1122011.8 filed Dec. 21, 2011 and United Kingdom Patent Application No. 1205382.3 filed Mar. 27, 2012.

DESCRIPTION OF INVENTION

The invention relates to a valve assembly, in particular to a valve assembly for use in a vehicle braking system in regulating the flow of pressurised fluid to a fluid pressure operated brake actuator.

Vehicle braking systems typically include a valve assembly known as a modulator which is connected to a source of pressurised fluid, the modulator being used to amplify the flow of pressurised fluid to and from a fluid pressure operated brake actuator. The modulator has a supply inlet which is connected to the source of pressurised fluid, a delivery port which is connected to the brake actuator and an exhaust outlet which is connected to the atmosphere (or any other low pressure volume), and can adopt a build position in which flow of fluid between the supply inlet and the delivery port is permitted, an exhaust position in which flow of fluid between the delivery outlet and the exhaust outlet is permitted, and a hold position in which flow of fluid between any two of the exhaust inlet, delivery port and exhaust outlet is substantially prevented.

In conventional braking systems, control of the modulator is achieved using a pressurised fluid signal known as the braking demand signal. When there is driver demand for braking, the driver typically operates a foot pedal, and movement of the foot pedal generates a fluid signal which is transmitted to a control inlet of the modulator. Receipt of the braking demand signal causes the modulator to move to the build position, so that the supply of pressurised fluid from the source of pressurised fluid to the brake actuator required to operate the vehicle brake commences. When the fluid pressure in the brake actuator approaches the pressure of the braking demand signal, the modulator moves to the hold or "lapped" position. Finally, when the driver releases the brake pedal, there is no longer demand for braking, the braking demand signal is removed, and the modulator reverts to the exhaust position, so that the pressurised fluid in the brake actuator acting to apply the vehicle brake is exhausted to the atmosphere.

If the vehicle is provided with anti-lock braking, the braking system includes at least one electrically operable valve which can override the braking demand signal. This is controlled using an electronic braking control unit (ECU) in accordance with conventional ABS control algorithms momentarily to release the brake pressure by moving the modulator to the exhaust position, or hold the brake pressure by moving the modulator to the hold position, even if there is braking demand, if wheel lock is detected.

In electronic braking systems, the braking system is provided with an electrically operable hold and an exhaust valve. Operation of the foot pedal generates an electrical braking demand signal, and this is transmitted to the ECU, which

operates the hold valve and exhaust valve to control the modulator to build, hold or release the pressure in the brake actuator as described above. In this case, supply of fluid to the control inlet is also from the supply of pressurised fluid.

According to a first aspect of the invention we provide a valve assembly comprising an inner housing in which is provided a first port, a second port, and a third port, there being located in the inner housing a valve member assembly which is movable between a first position in which the second port is connected to the third port whilst the first port is closed, a second position in which the first port is connected to the second port whilst the third port is closed, and a third position in which at least two of the first, second and third ports are closed, wherein the valve assembly further comprises an outer housing which is separate from and encloses at least part of the inner housing, the outer housing having a first port and a second port, the inner housing and outer housing each being provided with first mating parts, which engage to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the first port of the inner housing and the first port of the outer housing, and second mating parts, which engage to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the second port of the inner housing and the second port of the outer housing.

All modulators have some common standard features—the supply inlet, a delivery outlet and an exhaust port. The location and the size of the conduits which connect to the supply inlet, and delivery outlet may vary from system to system. The modulator may, for example, be located in a wheel-end unit, i.e. directly adjacent the wheel it is used to brake, or it may be located in a centrally located braking control unit for a truck or a trailer. A central vehicle braking control unit mounted on a truck may control operation of the truck brakes only.

Moreover, the delivery outlet may be connected to more than one working volume. For example, the number of brake actuators controlled by one modulator varies from system to system. It is common, for example, for all the brake actuators associated with wheels on one side of the vehicle to be controlled by a single modulator, whilst all the brake actuators associated with wheels on one side of the vehicle to be controlled by a different modulator. This is known as side-wise control, and it will be appreciated that in this arrangement the number of brake actuators controlled by each modulator depends on the number of braked wheels on the vehicle. Axle-wise control is also used—where a modulator controls the two brake actuators associated with the two wheels on a single axle. It is also known to use a combination of side-wise control and axle-wise control. For example, a braking system may include a modulator for controlling the braking of both wheels on the steering axle of the vehicle, a modulator for controlling the braking of the remaining wheels on the left-hand side of the vehicle, and a modulator for controlling the braking of the remaining wheels on the right-hand side of the vehicle. Alternatively, the modulator may be provided in a wheel end unit directly adjacent the single brake actuator it operates. It will, therefore be appreciated that the number of fluid connections to the delivery outlet varies from system to system.

Producing different configurations of modulator for all these different types of braking systems is inconvenient, but, by virtue of providing the modulator with an inner and outer housing, the configuration of the inner housing and valve member assembly may be standardised, whilst the configuration of the outer housing is tailored to fit a particular type of braking system. Volume production of modulators may therefore be simplified.

The inner housing may be provided with a fourth port flow which is connected to the valve member assembly such that the pressure of fluid at the fourth port controls movement of the valve member assembly between the first position, second position and the third position. In this case, preferably the outer housing is also provided with a third port and a third mating part which engages with a third mating part of the inner housing to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the fourth port of the inner housing and the third port of the outer housing.

By virtue of the provision of this fourth port, the modulator may be connected to a fluid pressure control signal, and the fluid pressure control signal used to control movement of the valve member assembly between the first, second and third positions.

Preferably the inner housing encloses a volume and the valve member assembly includes a movable element such as a piston or diaphragm which main chamber, the first, second and third ports extending into the main chamber, and the fourth port extending into the control chamber.

Preferably the first port and the fourth port are provided in the same side of the inner housing. In this case, the fourth port in the inner housing may comprise a generally annular aperture in the inner housing which surrounds and is substantially coaxial with the first port.

Moreover, the inner housing may be provided with a fifth port flow which is connected to the control chamber and the outer housing is also provided with a fourth port and a fourth mating part which engages with a fourth mating part of the inner housing to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the fifth port of the inner housing and the fourth port of the outer housing.

Preferably the first port, the fourth port and the fifth port are provided in the same side of the inner housing.

The outer housing may be provided with a plurality of ports in fluid communication with the second port of the inner housing.

The outer housing may be formed in two parts, the ports being provided in a first part of the outer housing, and electrical control components by means of which operation of the or each electrically operated valve may be effected being mounted on the second part.

The inner housing may be placed in the outer housing by translational movement in a first direction, and the inner housing secured relative to the outer housing by a locking means which comprises a locking part which engages with the surface of one or both of the inner housing and outer housing to prevent separation of the inner housing and outer housing, release of the locking means to permit separation of the inner housing and outer housing being achieved by sliding the locking part along said surface in a second direction generally perpendicular to the said first direction.

In one embodiment of the invention, the inner housing is secured relative to the outer housing by means of a bayonet connection.

In this case the inner housing may be provided with a male bayonet connector formation which is located in a corresponding recess provided in the outer housing.

Alternatively, the inner housing may be secured relative to the outer housing by means of a slide lock.

Embodiments of the invention will now be described with reference to the accompanying drawings of which,

FIG. **1** is a schematic illustration of an embodiment of the inner housing and valve member assembly suitable for use in a valve assembly according to the invention, the valve member assembly being in the exhaust configuration,

FIG. **2** is a schematic illustration of the portion of the valve assembly shown in FIG. **1** in the build configuration,

FIG. **3** is a schematic illustration of the portion of the valve assembly shown in FIG. **1** in the hold or lapped configuration,

FIG. **4** is a perspective view of an alternative configuration of the control piston suitable for use in a valve assembly according to the invention,

FIG. **5** is a schematic illustration of one embodiment of the control valve assembly for a valve assembly according to the invention,

FIG. ***6a*** is a perspective view of the inner housing and control valve assembly of a first embodiment of the valve assembly according to the invention,

FIG. ***6b*** is a plan view of the inner housing and control valve assembly shown in FIG. ***6a,***

FIG. ***6c*** is a cross-sectional view through the inner housing and control valve assembly shown in FIGS. ***6a*** and ***6b*** along the line A in FIG. ***6b,***

FIG. ***6d*** is a cross-sectional view through a first embodiment of valve assembly in accordance with the invention including the valve member assembly, inner housing, control valve assembly shown in FIGS. ***6a*** and ***6b***, and the outer housing, along the line B in FIG. ***6b,***

FIG. ***6e*** is a cross-sectional view through the first embodiment of valve assembly including the valve member assembly, inner housing and outer housing along the line C in FIG. ***6b,***

FIG. ***7a*** is a perspective view of the inner housing and control valve assembly of a second embodiment of valve assembly according to the invention.

FIG. ***7b*** is a plan view of the inner housing and control valve assembly shown in FIG. ***7a,***

FIG. ***7c*** is a part-cross-sectional perspective view through the inner housing and control valve assembly shown in FIGS. ***7a*** and ***7b*** along the line A in FIG. ***7b,***

FIG. ***7d*** is a cross-sectional view through the inner housing and control valve assembly shown in FIGS. ***7a*** and ***7b*** along the line A in FIG. ***7b,***

FIG. ***8a*** is a perspective view of the inner housing and control valve assembly of a third embodiment of valve assembly according to the invention,

FIG. ***8b*** is a plan view of the inner housing and control valve assembly shown in FIG. ***8a,***

FIG. ***8c*** is a part cross-sectional perspective view through the inner housing and control valve assembly shown in FIGS. ***8a*** and ***8b*** along the line A in FIG. ***8b,***

FIG. ***8d*** is a cross-sectional view through a first embodiment of the valve assembly in accordance with the invention including the valve member assembly, inner housing, control valve assembly shown in FIGS. ***6a*** and ***6b***, and the outer housing, along the line B in FIG. ***6b***,

FIG. **9** is a schematic illustration of an alternative embodiment of the inner housing and valve member assembly suitable for use in a valve assembly according to the invention, the valve member assembly being in the exhaust configuration,

FIG. **10** is a perspective illustration of the alternative embodiment of the inner housing and valve member assembly illustrated schematically in FIG. **9**, FIG. **11***a* is a perspective illustration of the inner housing and valve member assembly illustrated in FIGS. and **9** and **10** in an alternative embodiment of the outer housing, viewed from above,

FIG. **11***b* is a perspective illustration of the inner housing and valve member assembly illustrated in FIGS. and **9** and **10** in the alternative embodiment of the outer housing, viewed from below, and

FIG. **12** is a perspective illustration of the alternative embodiment of the outer housing illustrated in FIGS. **11***a* and **11***b*,

FIG. **13** is an illustration of a partial cross-section through a further alternative embodiment of the outer housing.

Referring now to the figures, there is shown a valve assembly **110**, comprising an inner housing **124** containing a valve member assembly, and being located, in part, within an outer housing **200**.

One embodiment of the inner housing **124** and valve member assembly suitable for use in the invention is illustrated schematically in FIGS. **1** to **5**, and together these are hereinafter referred to as a modulator **111**. It should be appreciated, however, that other configurations of the modulator (such as those described in GB 2407131 or GB 2467957) could equally be used with an outer housing in accordance with the invention.

In this example, the inner housing **124** is generally cylindrical, and is provided with a first port, hereinafter referred to as the supply inlet **112**, which is adapted to be connected to a source of pressurised fluid, typically a compressed air reservoir (not shown), a second port, hereinafter referred to as the delivery port **114**, which is adapted to be connected to a fluid pressure operated brake actuator (not shown), and third port, hereinafter referred to as the exhaust outlet **116**, which in this example vents to atmosphere. It will be appreciated that the exhaust outlet need not vent to atmosphere, and may instead be connected to an alternative low pressure volume which may be elsewhere in a vehicle braking system.

The modulator **111** is provided with a first movable member **126**, hereinafter referred to as the control piston **126**, which is movably mounted in the inner housing **124**. It should be appreciated that the control piston **126** need not be a piston—it could, for example, be a diaphragm. In this example, the control piston **126** divides the inner housing **124** into two chambers—a control chamber **122** and a main chamber **130**. The supply inlet **112**, delivery port **114**, and exhaust outlet **116** all provide access for fluid to flow into or out of the main chamber **130**, whilst a control port **123** is provided in the inner housing **124** to provide fluid flow into or out of the control chamber **122**.

In this example, the inner housing **124** has a generally cylindrical side wall **124***a*, a generally circular top face **124***b* which closes a first end of the side wall **124***a*, and an end cap **124***c*. In this example, the top face **124***b* is integral with the side wall **124***a*, whilst the end cap **124***c* is a separate component. A sealing element, in this example an O-ring **133**, is located between the end cap **124***c* and the side wall **124***a*, the sealing element substantially preventing flow of fluid into or out of the inner housing **124** other than via one of the supply inlet **112**, delivery port **114**, exhaust outlet **116** or control port **123**.

The exhaust outlet **116** is an aperture provided in the end cap **124***c*, whilst the supply inlet **112** and control port **123** are provided in the top face **124***b* of the inner housing **124**. The main chamber **130** is, however, located between the control piston **126** and the end cap **124***c*, and therefore, the control chamber **122** is located between the control piston **126** and the supply inlet **112**/delivery port **114**. As such, in order for the supply inlet **112** to communicate with the main chamber **130** rather than the control chamber **122**, a tubular extension **112***a* extends from around the aperture forming the supply inlet **112** into the control chamber **122**, through a generally central aperture **126***b* provided in the control piston **126**, and into the main chamber **130**. A free end **112***b* of the tubular extension **112***a* is therefore located in the main chamber **130**. A seal, in this example an O-ring **140**, is provided in a groove in the control piston **126** around the aperture **126***b*, to provide a substantially fluid tight seal between the control piston **126** and the outer diameter of the tubular extension **112***a*. Thus, movement of the control piston **126** relative to the modulator inner housing **124** is permitted whilst maintaining separation of the fluid in the control chamber **122** from fluid in the main chamber **130**.

The control chamber **122** is formed between the top face **124***b* of the inner housing **124** and the control piston **126**, the O-ring **128** in the control piston **126** engaging with the side wall **124***a* of the inner housing **124**. The side wall **124***a* of the inner housing **124** is provided with a delivery port **114** into the main chamber **130**, this aperture therefore providing the delivery port **114**. Two further sealing elements, in this example O-rings **125***a* & **125***b*, are mounted around the outer circumference of the side wall **124***a* of the inner housing, the delivery port **114** being located between the two sealing elements **125***a*, **125***b*.

A second movable member **132**, hereinafter referred to as the reservoir valve **132**, is provided in the main chamber **130**. The reservoir valve **132** is provided with a generally circular seat part **132***a* which is biased into engagement with the free end of the tubular extension **112***a* surrounding the supply inlet **112**, by means of a compression spring, hereinafter referred to as the reservoir spring **144**.

The free end of the tubular extension **112***a* is provided with a valve **112***b* formation—in this example a generally circular ridge, for engagement with the reservoir valve **132**. Moreover, an annular seat insert **132***c*, in this example made from a resilient rubber material, is provided in the seat part **132***a*. These assist in providing a fluid tight seal between the seat part **132***a* and the tubular extension **112***a* when the two are engaged, thereby closing the supply inlet **112**. It will be appreciated, of course, that a resilient seat insert could be provided on the free end **112***b* of the tubular extension **112***a*, and the valve formation on the reservoir valve **132**.

The reservoir valve **132** also includes a tubular locating part **132***b* which extends from the seat part **132***a* towards the end cap **124***c* of the inner housing **124**. The locating part **132***b* surrounds a portion of the reservoir spring **144** and extends between the seat part **132***a* and a supporting part **148** of the end cap **124***c*. The supporting part **148** is goblet shaped, in that it comprises a cup part **148***a* which has a generally circular base and sidewall which encloses a generally cylindrical space, and a stem part **148***b* which extends between the base of the cup part **148***a* and the end cap **124***c*.

The stem part **148***b* of the supporting part **148** is connected to the remainder of the inner housing **124** by means of (in this example two radially opposing) struts (not shown) which extend from the area of the end cap **124***c* surrounding the exhaust outlet **116** to the base of the stem part **148***b*, thus supporting the stem part **148***b* generally centrally in the exhaust outlet **116**, without impending flow of fluid through the exhaust part to any significant degree.

The locating part **132***b* of the reservoir valve **132** extends into the cup part **148***a* of the supporting part **148**, and has a seal **150** (again, in this example, an O-ring) provided around its outer surface. The O-ring **150** engages with the inner surface of the cup part **148***a* to provide a substantially fluid tight seal between the reservoir valve **132** and the end cap **124***c* whilst allowing the reservoir valve **132** to move against the biasing force of the reservoir spring **144** out of engagement with the tubular extension **112***a* around the supply inlet **112**.

So as to prevent fluid pressure at the supply inlet **112** exerting a net force on the reservoir valve **132** tending to push the reservoir valve **132** against the biasing force of the reservoir spring **144** and out of engagement with the tubular extension **112***a*, the reservoir valve **132** is provided with a throughbore which extends from a generally central portion of the seat part **132***a* enclosed by the seat insert **132***c* and connects the supply inlet **112** with the volume enclosed by the locating part **132***b* and the cup part **148***a* of the supporting part **148**. Two sides of the reservoir valve **132** are therefore exposed to the fluid at the supply inlet. **112**—the uppermost side of the seat part **132***a* and the lowermost side of the seat part **132***a* and locating part **132***b*.

Moreover, the diameter of the valve formation **112***b* is substantially equal to the inner diameter of the cup part **148***a* of the supporting part **148**. As such the area enclosed by the points of contact between the valve formation **112***b* and the seat insert **132***c* and the area enclosed by the points of contact between the O-ring **150** and the supporting part **148** are substantially equal. This ensures that, when the reservoir valve **132** is engaged with the tubular extension **112***a*, the two sides of the reservoir valve **132** exposed to the supply inlet fluid pressure are substantially equal in area, and the supply inlet fluid pressure exerts negligible net force on the reservoir valve **132**.

The control piston **126** is provided with a plurality of castellations **126***a* which are spaced around the generally central aperture **126***b* and extends towards the reservoir valve **132**. It will be appreciated that engagement of the castellations **126***a* with the reservoir valve **132** sets a minimum spacing between the control piston **126** and the reservoir valve **132**.

The modulator **111** is also provided with a third movable member **152**, hereinafter referred to as the exhaust valve **152**. The exhaust valve **152** has a tubular body **152***a* which surrounds the cup part **148***a* of the supporting part **148**. A seal **154**, in this example an O-ring, is located in a groove around the radially inward facing surface of the tubular body **152***a* and provides a substantially fluid tight seal between the exhaust valve **152** and the outer surface of the cup part **148***a* of the supporting part **148**, whilst allowing the exhaust valve **152** to slide longitudinally relative to the supporting part **148**.

At the end of the tubular body **152***a* adjacent the end cap **124***c*, there is provided a radially outwardly and inwardly extending flange part which provides support for an exhaust seat insert **152***b*. Preferably, the exhaust seat insert **152***b* is made from a resilient material such as rubber. The exhaust valve **152** is movable relative to the inner housing **124** to bring the exhaust seat insert **152***b* into and out of engagement with a valve formation, which comprises a generally circular ridge **116***a* which extends into the main chamber **130** from the portion of the end cap **124***c* surrounding the exhaust outlet **116**. Engagement of the exhaust valve **152** with the end cap **116** in this way substantially prevents flow of fluid through the exhaust outlet **116**. It will be appreciated, of course, that a resilient seat insert may be provided on the end cap **124***c* of the inner housing **124** around the exhaust port **116**, and the valve formation on the exhaust valve **152**.

A mechanical link is provided between the control piston **126** and the exhaust valve **152**. In this example, the link comprises a plurality of connecting rods **156** which extend from the control piston **126** into the main chamber **130** to the exhaust valve **152**.

The other end of the tubular body **152***a* of the exhaust valve **152**, i.e. the end adjacent the control piston **126**, is provided with a radially outwardly extending connection flange **152***c*. A series of apertures are provided in this connection flange **152***c*, generally equally spaced around the circumference of the tubular body **152***a*. Through each of these apertures extends a connecting rod **156**. Each connecting rod **156** has a first end **156***a* which is secured to the control piston **126**, and a second end which is provided with a stop part **156***b* which extends generally perpendicular to the longitudinal axis of the connecting rod **156**. It will be appreciated that, to simplify manufacture of the modulator **111**, the connecting rods **156** cannot be integral with the control piston **126**, and advantageously either the connecting rods **156** are fastened to the control piston, or the stop part **156***b* is fastened to the connecting rods **156**.

The exhaust valve **152** is also provided with a stop part **152***d* which comprises a flange which extends radially outwardly from the tubular body **152***a* and which is located between the exhaust seat insert **152***b* and the connection flange **152***c*. The connecting rods **156** can slide in the apertures, and therefore movement of the control piston **126** relative to the exhaust valve **152** is permitted, but it will be appreciated that engagement of the stop parts **156***b* of the connecting rods **156** with the connection flange **152***c* sets a maximum spacing between the control piston **126** and the exhaust valve **152**, and engagement of the stop parts **156***b* of the connecting rods **156** with the stop part **152***d* of the exhaust valve **152** sets a minimum spacing between the control piston **126** and the exhaust valve **152**.

An alternative configuration of this link is illustrated in FIG. **4**, which shows a perspective view of an alternative embodiment of the control piston **126'** from the main chamber side of the piston. In this version, the link is provided by four U-shaped legs **156'**, the base part of which is provided with a radially inwardly extending lip formation **156***b*'. In this case, the connection flange **152***c* of the exhaust valve **152** is not provided with a series of apertures, and the legs **156'** lie radially outwardly of the connection flange **152***c* with the lip formation **156***b*' extending into the space between the connection flange **152***c* and the stop part **152***d*. Advantageously, the legs **156'** are sufficiently flexible and resilient that, during assembly of the modulator **111**, the legs **156'** may be bent slightly to force the lip formations **156***b*' over the connection flange **152***c* until the lip formation **158***b*' snaps into place in the space between the connection flange **152***c* and the stop part **152***d*.

It should be appreciated that, whilst in these embodiments of the invention the link between the control piston **126** and the exhaust valve **152** comprises a longitudinal element—the connecting rods **156** or legs **156'**, which is fixed to the control piston **128**, and radially outwardly extending flanges which are provided on the exhaust valve and form the stop parts **152***d* and **156***b*, the longitudinal link element may be provided on the exhaust valve **152** and the stops on the control piston **126**.

The diameter of the valve formation **116***a* surrounding the exhaust outlet **116** which engages with the exhaust seat insert **152***b* is deliberately selected to be greater than the diameter of the cylindrical space enclosed by the tubular body **152***a* of the exhaust valve **152**. This means that, the area enclosed by the points of contact between the exhaust valve formation **116***a* and the exhaust seat insert **152***b* is greater than the area enclosed by the points of contact between the O-ring **154** and the cup part **148***a* of the supporting part **148**. As such, when the exhaust valve **152** is engaged with this ridge, the fluid pressure in the main chamber **130** exerts a net force on the exhaust valve **152** which pushes the exhaust valve **152** into engagement with the exhaust valve formation **116***a*.

In one embodiment of the invention, the difference in diameter is selected so that the force pushing the exhaust valve **152** into engagement with the end cap **124***c* of the inner housing **124** (i.e. the exhaust seat energisation) is around 1 N/mm when the pressure in the main chamber is 10 bar. It will be appreciated, however, that this difference can be tailored to give whatever seat energisation is required—either higher or lower, without having any effect on the cracking pressure of the modulator **111**.

A spring **158** is provided between the control piston **126** and the exhaust valve **152**. This spring, hereinafter referred to as the exhaust spring **158**, is, in this example, a helical compression spring, extends from the control piston **126** to the connection flange **152***c* of the exhaust valve **152**, and is located radially inwardly of the connecting rods **156**, around the tubular extension **112***a* and a portion of the reservoir valve **132**.

Flow of fluid between the supply inlet **112**, the delivery port **114** and the exhaust port **116** is controlled by movement of the control piston **126** under the influence of fluid pressure in the control chamber **122**, as in prior art modulators. In this example, a conventional electrically operated control valve assembly **200**, comprising three solenoid operated valves is provided to control flow of pressurised fluid into the control chamber **122**. For simplicity, in FIGS. **1**, **2** and **3**, only one inlet for supply of fluid to and from the control chamber **122** is shown—the control port **123** in the top face **124***b* of the inner housing **124**, and the control valve assembly **200** has been omitted. The preferred embodiment of the invention is slightly more complex than this, however, and requires at least two ports into the control chamber **122**.

FIG. **5** is a schematic illustration of the preferred embodiment of control valve assembly **200**. This shows a portion of the modulator **111** including the top face **124***b* of the inner housing **124**, the supply inlet **112** and its connection to a reservoir of pressurised fluid **202**, and the control piston **126**. It also shows a first solenoid operated valve **204**, hereinafter referred to as the hold valve **204**, a second solenoid operated valve **206**, hereinafter referred to as the dump valve **206**, and a third solenoid operated valve **208**, hereinafter referred to as the pneumatic back-up valve **208**.

Each of these valves **204**, **206**, **208** has an inlet **204***a*, **206***a*, **208***a*, an outlet **204***b*, **206***b*, **208***b* and a valve member **204***c*, **206***c*, **208***c*. Each valve member **204***c*, **206***c*, **208***c* is mounted in a cylindrical support housing **204***d*, **206***d*, **208***d* and is movable between an open position in which flow of fluid between the inlet **204***a*, **206***a*, **208***a* and the outlet **204***b*, **206***b*, **208***b* is permitted, and a closed position in which flow of fluid between the inlet **204***a*, **206***a*, **208***a* and the outlet **204***b*, **206***b*, **208***b* is substantially prevented. Each valve **204**, **206**, **208** is provided with a biasing means such as a helical spring (not shown) which, in the case of the hold and dump valves **204**, **206**, biases the valve member **204***c*, **206***c* into the closed position, and which, in the case of the pneumatic back-up valve **208**, biases the valve member **208***c* into the open position.

Each valve **204**, **206**, **208** is also provided with a solenoid **204***h*, **206***h*, **208***h* which is mounted around the circumference of the support housing **204***d*, **206***d*, **208***d*, and each valve member **204***c*, **206***c*, **208***c* is constructed such that passage of an electrical current through the solenoid **204***h*, **206***h*, **208***h* causes the valve member **204***c*, **206***c*, **208***c* to move against the biasing force of the spring to the open position in the case of the hold and dump valves **204**, **206** and to the closed position in the case of the pneumatic back-up valve **208**. The flow of electrical current to the solenoids **204***h*, **206***h*, **208***h* is typically controlled by an electronic braking control unit.

The inlet **206***a* of the dump valve **206** is connected to the control chamber **122** via the control port **123**, as are the outlets **204***b*, **208***b* of the hold valve **204** and the pneumatic back-up valve **208**. The inlet **204***a* of the hold valve **204** is connected to the pressurised fluid reservoir **202** via the supply inlet **112**, the inlet **208***a* of the pneumatic back-up valve **208** is connected to a fluid flow line carrying a fluid pressure braking signal from a brake pedal **210**, and the outlet **206***b* of the dump valve **206** vents to a low pressure region, typically atmosphere.

The modulator **111** operates as follows.

When electronic braking control is demanded, the pneumatic back-up valve **208** is closed, by the supply of electrical current to the solenoid of this valve **208**.

When there is no braking demand, the modulator **111** adopts the exhaust configuration as illustrated in FIG. **1**. An electrical current is supplied to the solenoid of the dump valve **206**, but not to the hold valve **204**. The hold valve **204** is therefore closed. The control chamber **122** is thus vented to atmosphere, and the control piston **126** is located such that the volume of the control chamber **122** is at a minimum. The reservoir seat part **132***a* is engaged with the tubular extension **112***a* of the supply inlet **112** so that flow of fluid from the supply inlet **112** into the main chamber **130** is substantially prevented, and the exhaust seat insert **152***b* is spaced from the end cap **124***c* of the inner housing **124** such that flow of fluid from the delivery port **114** to the exhaust outlet **116** is permitted.

When a braking demand signal is received, an electrical current is supplied to the solenoid of the hold valve **204**, but not the dump valve **206**. The hold valve **204** thus directs pressurised fluid from the reservoir **202** to the control chamber **122** via the control port **123** and control inlet **123***a*. The control piston **126** is acted on by the increasing pressure in the control chamber **122** and is pushed towards the reservoir valve **132** and the exhaust valve **152**. The force from the pressure in the control chamber **122** is transmitted to the exhaust valve **152** via the exhaust spring **158**, and as the control piston **126** moves to increase the volume of the control chamber **122**, the exhaust valve **152** moves with it, until the exhaust seat insert **152***b* engages with the ridge around the exhaust outlet **116**. Fluid flow through the exhaust outlet is thus substantially prevented.

As the pressure in the control chamber **122** increases further, the exhaust spring **158** is compressed as the control piston **126** continues to move to further increase the volume of the control chamber **122**. The castellations **126***a* on the control piston **126** then engage with the reservoir valve **132** and push the reservoir seat part **132***a* out of engagement with the tubular extension **112***a* so that flow of fluid through the supply inlet **112** to the main chamber **130** and then to the delivery port **114** is permitted. The stop parts **156***b* on the connecting rods **156** then engage with the stop part **152***d* on the exhaust valve **152** to bring movement of the control piston **126** to a stop. The modulator is then in the build configuration as illustrated in FIG. **2**.

It will be appreciated that the height of the castellations **126***a* is selected to ensure that the exhaust valve **152** is engaged with the end cap **124***c* of the inner housing **124**, thus closing the exhaust outlet **116**, before the castellations **126***a* engage with the reservoir valve **132**. If this was not the case, the supply inlet **112** and the exhaust port **116** would be open at the same time, which would result in venting of the pressurised fluid supply to the atmosphere. Similarly, it will be appreciated that the separation of the stop part **152***d* and connection flange **152***c* of the exhaust valve **152** is selected such that the stop parts **156***b* of the connecting rods **156** do not engage with the stop part **152***d* of the exhaust valve **152** until the control piston **126** has pushed the reservoir valve **132** far enough away from the tubular extension **112***a* to ensure substantially unimpeded flow of fluid through the supply inlet **112**.

If the exhaust valve **152** should stick, so that, as the pressure in the control chamber **122** builds, it doesn't move and, instead, the exhaust spring **158** is compressed, it is possible that the castellations **126***a* could engage with the reservoir valve **132** to open the supply inlet **112** whilst the exhaust port **116** is still open. The stop part **152***d* on the exhaust valve **152** mitigates this problem, because, as the exhaust spring **158** is compressed, the stop parts **156***b* of the connecting rods **156** engage with the stop part **152***d* of the exhaust valve **152** when the supply inlet **112** is partially open. This either forces the exhaust valve **152** to move to close the exhaust outlet **116**, or prevents further movement of the control piston **126** and the supply inlet **112** being fully opened.

In order to move the modulator **111** to the hold configuration illustrated in FIG. **3**, in which both the exhaust outlet **116** and the supply inlet **112** are closed, electrical current is supplied to neither the hold valve **204** or the dump valve **206**. Flow of pressurised fluid into the control chamber **122** is stopped, and the control chamber **122** is closed. As fluid continues to flow through the supply inlet **112** to the delivery outlet **114**, fluid pressure in the main chamber **130** increases, and acts on the control piston **126** pushing it to reduce the volume of the control chamber **122**. The reservoir valve **132** is therefore free to move towards the control piston **126** under the action of the reservoir spring **144**, until the annual seat insert **132***c* engages with the tubular extension **112***a* to close the supply inlet **112** again. As this stops the flow of pressurised fluid into the main chamber **130**, movement of the control piston **126** stops at an equilibrium position when the force exerted on the control piston **126** by fluid pressure in the control chamber **122** balances the force exerted by fluid pressure in the main chamber **130**.

The modulator **111** is returned to the exhaust configuration by the supply of an electrical current to the dump valve **206** to vent the control chamber **122** to atmosphere. The control piston **126** is then able to move under the influence of the fluid pressure in the main chamber **130** to minimise the volume of the control chamber **122**, and engagement of the stop parts **156***b* of the connecting rods **156** with the connection flange **152***c* of the exhaust valve **152** causes the exhaust valve **152** to be pulled out of engagement with the end cap **124***c* of the inner housing **124**, and therefore the exhaust port **116** opened.

The pneumatic back-up valve **208** only opens if the electrical power supply to the braking system fails, and electronic braking control is no longer available. In the absence of an electrical current, the pneumatic back-up valve **208** automatically opens, and connects the control chamber **122** to the fluid pressure braking signal. The control piston **126** then moves under the influence of the fluid pressure braking control signal.

As mentioned above, in order to simplify the above explanation of the construction and operation of the modulator **111**, the schematic illustrations in FIGS. **1**, **2**, **3**, and **5** show a simplified arrangement of the control valve assembly **200**, pressure transducer port **212** and control port **123**. In a first embodiment of the invention, these parts are arranged as illustrated in FIGS. **6***a*, **6***b*, **6***c*, and **6***d*.

Referring now to FIGS. **6***a* to **6***e*, these show the inner housing **124** with the support housings **204***d*, **206***d*, **208***d* of the hold valve **204**, dump valve **206** and pneumatic back-up valve **208** secured to the top face **124***b* of the inner housing **124**, in this example, by means of fasteners such as bolts or screws. The supply inlet **112** comprises a cylindrical tube which is integrally formed with the top face **124***b* of the inner housing **124** and extends normally from the centre of the top face **124***b* of the inner housing. A seal **214**, in this example an O-ring, is mounted around the supply inlet, supported by a shoulder **216** in the inner housing **124** which extends radially outwardly of the supply inlet **112**. Either side of the supply inlet **112** are located a control inlet **123***a* and a control exhaust **123***b* which, in this example, are also cylindrical tubes which are integrally formed with the top face **124***b* of the inner housing **124**. Seals **218**, **220** are, again in this example O-rings, are mounted around the control inlet **123***a* and control exhaust **123***b* respectively, supported by a shoulder **216** in the inner housing **124** which extends radially of the control inlet **123***a* and control exhaust **123***b*.

As best illustrated in FIG. **6***b*, the supply inlet **112**, control inlet **123***a* and control exhaust **123***b* lie on a generally straight line with the supply inlet **112** between the control inlet **123***a* and control exhaust **123***b*. The hold valve **204** and pressure transducer port **212** lie on one side of this line, whilst the dump valve **206** and pneumatic back-up valve **208** lie on the other side of this line, the dump valve **206** being adjacent the control exhaust **123***b* and the pneumatic back-up valve **208** being adjacent the control inlet **123***a*.

As best illustrated in FIGS. **6***c* and **6***d*, each valve member **204***c*, **206***c*, **208***d* of the control valve assembly **200** is mounted in a cylindrical valve space **204***e*, **206***e*, **208***e* enclosed by a side wall integrally formed with the top face **124***b* of the inner housing **124**. Three apertures are provided in the top face **124***b* of the inner housing **124**, each connecting one of the cylindrical valve spaces **204***e* **206***e*, **208***e* with the control chamber **122**. The apertures therefore form the outlet **204***b*, **206***b*, **208***b* of the hold valve **204**, dump valve **206** and pneumatic back-up valve **208** respectively. A slight ridge in the top face **124***b* of the inner housing **124** around the aperture provides a valve seat, and, when in the closed position, each valve member **204***c*, **206***c*, **208***c* is engaged with this seat to substantially prevent flow of fluid between the cylindrical valve space **204***e*, **206***e*, **208***e* and the control chamber **122**.

Each support housing **204***d*, **206***d*, **208***d* comprises a tube which extends around the valve member **204***c*, **206***c*, **208***c* into the cylindrical valve space **204***e*, **206***e*, **208***e*, a substantially fluid tight seal, in this example an O-ring, being provided between the support housing **204***d*, **206***d*, **208***d* and the top face **124***b* of the inner housing **124**. The resilient biasing element in this example comprises a helical spring **204***g*, **206***g*, **208***g* which is located in the cylindrical valve space **204***e*, **206***e*, **208***e* around the end of the valve member **204***c*, **206***c*, **208***c* adjacent the outlet **204***b*, **206***b*, **208***b*. The spring **204***g* of the hold valve **204** extends between a shoulder provided on the valve member **204***c* and the support housing **204***d* so as to bias the valve member **204***c* into engagement with the valve seat, as does the spring **206***g* of the dump valve **206**. In contrast, the spring **208***g* of the pneumatic back-up valve **208** extends between a shoulder provided on the valve member **208***c* and the top face **124***b* of the inner housing **124**, so as to bias the valve member **208***c* out of engagement with the valve seat.

In this example, the inner housing **124** is also provided with a pressure transducer port **212** which is integrally formed in the top face **124***b* of the inner housing **124** and extends from the top face **124***b* of the inner housing **124** into the main chamber **130** via an aperture provided in the side wall **124***c* of the inner housing **124**.

As best illustrated in FIG. **6***b*, four connecting passages are integrally formed in the top face **124***b* of the inner housing **124**. The first connecting passage **222** connects the cylindrical valve space **204***e* of the hold valve **204** with the supply inlet **112**, and thus forms the inlet **204***a* of the hold valve. The second connecting passage **224** connects the cylindrical valve space **206***e* of the dump valve **206** with the control exhaust **123***b* and thus forms the inlet **206***a* of the hold valve. The third connecting passage **226** connects the cylindrical valve space **208***e* of the pneumatic back-up valve **208** with the control inlet **123***a*, and thus forms the inlet **208***a* of the pneumatic back-up valve **208**. Finally, the fourth connecting passage **228** connects the pressure transducer port **212** to the main chamber **130**.

It will be appreciated that these connecting passages **222**, **224**, **226**, **228** complete the connections illustrated schematically in FIG. **5**, and allow the modulator **111** to be operated as described above.

In order to provide connections to a vehicle braking system, an outer housing **230**, which is illustrated in FIGS. **6***d* and **6***e*, is mounted over the inner housing **124**. In this embodiment of the invention, the outer housing **230** comprises a top cap which encloses the side wall **124***a* and top face **124***b* of the inner housing **124**, the end cap **124***c* extending out of and not being enclosed by the outer housing **230**. The top cap of the outer housing **230** includes a generally cylindrical side wall **230***a* which engages with the two seals **125***a*, **125***b* to provide a substantially fluid tight seal. The top cap of the outer housing **230** also includes a top face **230***b* which closes one end of the side wall **230***a*.

The top cap of the outer housing **230** is provided with a delivery port **232** which extends from the exterior of the outer housing **230** through the side wall **230***a* and into the annular space between the side walls of the inner housing **124** and outer housing **230** and the two seals **125***a*, **125***b*. The top cap of the outer housing **230** is also provided with a supply port **234** which comprises a tube integrally formed with the top face **230***b* of the outer housing **230**. This extends from the exterior of the outer housing **230** to engage with the seal, O-ring **214**, around the supply inlet **112** in the inner housing **124**. By virtue of this seal **214**, the supply port **234** and supply inlet **112** together provide a substantially fluid tight conduit between main chamber **130** of the valve member assembly and the exterior of the outer housing **230**.

Whilst the outer housing **230** may comprise just a top cap which provides a first port and a second port with a first and a second mating part to engage with the supply inlet **112** and the delivery port **114** of the modulator, in this case, as the modulator also includes a control inlet **123***a* and a control exhaust **123***b*, the top cap also provides ports and mating parts to engage with the control inlet **123***a* and control exhaust **123***b*.

In this example, the top cap of the outer housing **230** is also provided with a control port **236** which comprises a tube integrally formed with the top face **230***b* of the outer housing **230**. This extends from the exterior of the outer housing **230** to engage with the seal, O-ring **218**, around the control inlet **123***a* in the inner housing **124**. Similarly, in this example, the top cap of the outer housing **230** is also provided with an exhaust port **238** which comprises a tube integrally formed with the top face **230***b* of the outer housing **230**. This extends from the exterior of the outer housing **230** to engage with the seal, O-ring **220**, around the control exhaust **123***b* in the inner housing **124**. By virtue of these seals **218**, **220**, the control port **236** and control inlet **123***a* together and the exhaust port **238** and control exhaust **123***b* together both provide a substantially fluid tight conduit between the exterior of the outer housing **230** and the control chamber **122** of the valve member assembly, via the back-up valve **208** and dump valve **206** respectively.

In this example, the side wall **230***a* of the outer housing **230** is made from die cast metal, whilst the top face **230***b* is made from a polymer, an O-ring **246** being provided to ensure a substantially fluid tight seal between the two parts of the outer housing **230**.

An electronic circuit board (ECB) **240** is mounted in the top cap of the outer housing **230** so that it lies between the top faces **124***b*, **230***b* of the inner **124** and outer **230** housings. The electrical solenoids **204***h*, **206***h*, **208***h* required for operating the hold valve **204**, dump valve **206** and pneumatic back-up valve **208** respectively are mounted on the ECB **240**, so that they envelope their respective support housing **204***d*, **206***d*, **208***d* (best illustrated schematically in FIG. **5**). A pressure transducer **244** is also mounted on the ECB **240** so that it engages in a fluid tight manner with the pressure transducer port **212** and can therefore measure the fluid pressure in the main chamber **130**.

The ECB **240** includes the required electronic connections and components for controlling flow of an electrical current to the solenoids **204***h*, **206***h*, **208***h*, and for obtaining an electrical pressure signal from the pressure transducer **244**. An electrical connector **242** is provided on the outer housing **230** and this provides an external electrical connection to the ECB **240**. Preferably the electrical connector **242** is configured to be connectable to a four pin CAN bus.

Thus, when the valve assembly **110** is used in a vehicle braking system, the supply port **234** is connected to a source of pressurised fluid, a compressed air reservoir for example, the control port **236** is connected to the source of a fluid pressure braking demand signal, the delivery port **232** is connected to a fluid pressure operated brake actuator, and the electrical connector **242** is connected to the main electronic control unit of the braking system.

An alternative configuration of the valve assembly **110** is illustrated in FIGS. **7***a*, **7***b*, **7***c* and **7***d* In this configuration, the supply inlet **112** also comprises a tube which is integrally formed with the top face **124***b* of the inner housing **124**, but differs from the embodiment of the invention illustrated in FIGS. **6***a*, **6***b*, **6***c* and **6***d* in that the supply inlet **112** extends initially normally from the centre of the top face **124***b* of the inner housing **124**, but then bends through around 90° and extends towards the circumference of the top face **124***b*. A seal **214**, in this example an O-ring, is mounted in a groove around the end of the supply inlet **112**, which lies on a diagonal at around 45° to and facing up from the top face **124***b* of the inner housing **124**. This engages with a correspondingly angled face of the supply port **234** of the outer housing **230**.

Moreover, the control inlet **123***a*, is again integrally formed with the top face **124***b* of the inner housing **124**, but extends from the valve space **208***e* of the pneumatic back-up valve **208** towards the circumference of the top face **124***b*. A seal **218**, in this example an O-ring, is mounted in a groove around the end of the control inlet **123***a*, which also lies on a diagonal at around 45° to and facing up from the top face **124***b* of the inner housing **124**. As with the supply inlet **112**, this engages with a correspondingly angled face of the control port **236** of the outer housing **230**.

Finally, in this embodiment of the invention, the control exhaust **123***b* extends from the valve space **206***e* of the dump valve **206** generally normally from the top face **124***b* of the inner housing **124**. The exhaust port **238** of the outer housing comprises a tube which is integrally formed in the top face

230*b* of the outer housing **230** and extends from the exterior of the outer housing **230** into the control exhaust **123***b* in the inner housing **124**.

A third embodiment of the valve assembly **110** is illustrated in FIGS. **8***a*, **8***b*, **8***c* and **8***d*. Again, this embodiment of the invention differs from the previous version only in relation to the configuration of the supply inlet **112**, control inlet **123***a* and control exhaust **123***b* in the inner housing **124**, and the manner of their engagement with the supply port **234**, control port **236** and exhaust port **238** in the outer housing **230**. In this case, the configuration is very similar to the first embodiment illustrated in FIGS. **6***a*, **6***b*, **6***c*, **6***d*, and **6***e* in terms of the positioning of the supply inlet **112**, the control inlet **123***a* and the control exhaust **123***b*. In this embodiment, however, the seals with the outer housing **230** are all radial seals. In other words, each of the supply inlet **112**, control inlet **123***a* and the control exhaust **123***b* comprises a tube which is integrally formed with and extends generally perpendicular to the top face **124***b* of the inner housing **124**. The supply port **234**, control port **236** and exhaust port **238** also each comprise a tube which is integrally formed with and extends generally perpendicular to the top face **230***b* of the outer housing **230** to surround the supply inlet **112**, control inlet **123***a* and control exhaust **123***b* respectively. The O-rings **214**, **218** and **220** are all mounted around the outer surface of the supply inlet **112**, control inlet **123***a* and control exhaust **123***b* respectively and engage with the inner surface of the tube of the supply port **234**, control port **236** and exhaust port **238** respectively, so as to provide a substantially fluid tight seal between the adjacent parts. By virtue of this arrangement all the seals between the inner housing **124** and the outer housing **230** are between surfaces which extend generally parallel to the side walls **124***a* and **230***a* of the inner **124** and outer housings **230**. This means that some sliding movement of the inner housing **124** with respect to the outer housing **230** can be accommodated without the integrity of these seals being compromised.

Whilst in the embodiments of the invention described above, the outer housing **230** has only one delivery port **232**, it should be appreciated that more than one port into the annular space between the housings **124**, **230** and the two O-rings **125***a*, **125***b* may be provided in the outer housing **230**. When used in a vehicle braking system, this enables the valve assembly **110** to provide pressurised fluid to more than one brake actuator. Significantly, to do this, requires only a change in the configuration of the outer housing **230**. Thus, the same modulator **111** may be used regardless of how many brake actuators the valve assembly **110** is intended to control.

Similarly, by virtue of the use of an outer housing **230** the positions of the connections to the source of pressurised fluid (i.e. the supply port **234**), and the fluid pressure braking demand signal (i.e. the control port), may be varied to accommodate different configurations of vehicle braking system, using a standard modulator **111** and by changing the configuration of the outer housing **230** only.

The outer housing **230**, or at least the side walls **230***a* of the outer housing **230**, may also be configured to receive and provide fluid connections to more than one modulator **111**.

Whilst the outer housing **230** may comprise only the top cap, in these examples it also comprises a bottom cap **230***c* which covers the end cap **124***c* of the inner housing **124** of the modulator **111**. The bottom cap **230***c* has one or more apertures through which fluid passing through the exhaust port **116** of the modulator may vent, and may also provide support for a valve member **250** such as that described in GB 2467958, which is designed to limit water/contaminant ingress into the modulator whilst permitting free flow of fluid out of the exhaust port **116**.

An alternative embodiment of inner housing **124'** is illustrated schematically in FIG. **9**, and in perspective view in FIG. **10**. This embodiment of inner housing **124'** also has a generally cylindrical side wall **124***a*', and a generally circular top face **124***b*' which closes a first end of the side wall **124***a*', and an end cap **124***c*'. Again, in this example, the top face **124***b*' is integral with the side wall **124***a*', whilst the end cap **124***c*' is a separate component. A sealing element, in this example an O-ring **133'**, is located between the end cap **124***c*' and the side wall **124***a*', the sealing element substantially preventing flow of fluid into or out of the inner housing **124'** other than via one of the supply inlet **112'**, delivery port **114'**, exhaust outlet **116'** or control port **123'**.

As in the first embodiment of inner housing **124** described above, the exhaust outlet **116'** is an aperture provided in the end cap **124***c*', whilst the supply inlet **112'** and control port **123'** are provided in the top face **124***b*' of the inner housing **124'**. In this embodiment of inner housing **124'**, however, the control port **123'** is formed by an annular aperture which surrounds, and is coaxial with, the supply inlet **112'**.

Moreover, in this embodiment of inner housing, the end cap **124***c*' is provided with a plurality of bayonet connector formations **300** which are spaced around an outer surface of the end cap **124***c*', and which extend generally perpendicular to the longitudinal axis A of the valve assembly **110'**.

This alternative embodiment of the valve assembly **110'** is placed in an outer housing **230'**, which is illustrated in FIGS. **11***a*, **11***b* and **12**. Again, the outer housing **230'** comprises a top cap which encloses the side wall **124***a*' and top face **124***b*' of the inner housing **124'**, the end cap **124***c*' extending out of the outer housing **230'**. In this embodiment of the invention, however, the end cap **124***c*' of the valve assembly **110'** is partially enclosed by the top cap of the outer housing **230'**.

Again, the top cap of the outer housing **230'** includes a generally cylindrical side wall **230***a*' which engages with the two seals **125***a*', **125***b*' to provide a substantially fluid tight seal, and a top face **230***b* which closes one end of the side wall **230***a*.

The top cap of the outer housing **230'** is provided with a delivery port (not shown) which extends from the exterior of the outer housing **230'** through the side wall **230***a*' and into the annular space between the side walls of the inner housing **124'** and outer housing **230'** and the two seals **125***a*', **125***b*'.

The top cap of the outer housing **230'** is also provided with a supply port **234'** which comprises a tube integrally formed with the top face **230***b*' of the outer housing **230'**. This extends from the exterior of the outer housing **230'** to engage with the seal around the supply inlet **112'** in the inner housing **124'**. By virtue of this seal, the supply port **234'** and supply inlet **112'** together provide a substantially fluid tight conduit between the main chamber **130** of the valve member assembly **110'** and the exterior of the outer housing **230'**.

Moreover, the top cap of the outer housing **230'** is also provided with a control port **236'** which comprises an annular aperture which surrounds and is coaxial with the supply port **234'**. Again, this extends from the exterior of the outer housing **230** and the edges of this annular aperture engage with the seals around the control inlet **123***a*' in the inner housing **124'**. By virtue of these seals, the control port **236'** and control inlet **123***a*' together provide a substantially fluid tight conduit between the exterior of the outer housing **230** and the control chamber **122** of the valve member assembly.

This embodiment of the invention is not provided with a separate control exhaust, so fluid flow through the control port

236' is, in this embodiment, bi-directional, with fluid from the control chamber being exhausted through the control port 236'.

Again, an electronic circuit board (ECB) may be mounted in the top cap of the outer housing 230' so that it lies between the top faces 124b', 230b' of the inner 124' and outer 230' housings, just as described above.

This embodiment of outer housing 230' is provided with bayonet receiving formations 310 to engage with the bayonet connector formations 300 provided on the inner housing 124'. The bayonet receiving formations 310 comprise generally of L-shaped recesses in the interior surface of the side wall 230a' of the outer housing 230' at the end of the side wall 230a' opposite to the top face 230b'.

The valve assembly 110' is secured in the outer housing 230' by the conventional manner of using bayonet connectors, i.e. by pushing the valve assembly 110', top face 124b' first into the outer housing 230', orienting the valve assembly 110' so that the bayonet connector formations 300 slot into the bayonet receiving formations 310, and then rotating the valve assembly 110' relative to the outer housing 230'. In this way, the valve assembly 110' can only be removed from the outer housing 230' by rotating the valve assembly 110' back in the opposite direction. In use, the valve assembly 110' and outer housing are typically arranged with the top faces 124b', 230b' of the inner housing 124' and the outer housing 230', uppermost, so the valve assembly 110' is supported in the outer housing 230' by the bayonet connector formations 300.

It will be appreciated, of course, that, whilst in this example, the inner housing 124' is provided with the male bayonet connector formations 300, and the outer housing 230' with the female bayonet receiving formations 310, this need not be the case. The male bayonet connector formations 300 could equally be provided on the interior surface of the outer housing 230' and the bayonet receiving formations 310 on the exterior of the inner housing 124'.

Arranging the control port 123' coaxially with the supply port 112' facilitates the use of a bayonet-type connection between the inner housing 124' and outer housing 230', as this means that it is not necessary for the inner housing 124' to be in one particular orientation relative to the outer housing 230' for the control port 236' to be connected to the control inlet 123a'.

The use of a bayonet connector formation may be advantageous over the use of bolts to secure the inner housing of the modulator with respect to the outer housing, as a user could undo the bolts when the modulator is pressurised, and in this case, the pressure of fluid at the delivery port could cause one or both parts to fly off and injure the user. In contrast, when a bayonet connector formation is employed, fluid pressure at the delivery port exerts a force to separate the inner and outer housing. This pushes the bayonet connector formation hard against the bayonet receiving formation, with the result that the frictional forces between the two parts are so high that it is very difficult for a user to carry out the relative rotation of the parts required to separate them.

To further improve the locking of the outer housing with respect to the inner housing, one of the bayonet connector formation or the bayonet receiving formation may be provided with a small recess, and the other with a corresponding protuberance, the protuberance locating in the recess in a "click fit" arrangement when the two parts are in the desired orientation. This will further increase the force required to rotate the outer housing with respect to the inner housing when the modulator is pressurised.

This advantage can also be achieved with other locking arrangements in which; to disengage the outer housing and inner housing, a locking part must be slid over a surface generally perpendicular to the direction in which the inner housing is moved relative to the outer housing when placed in the outer housing. For example, a slide lock, as illustrated in FIG. 13, may be used.

In this embodiment, both the inner housing and outer housing are provided with a radially outwardly extending flange 400, 410, which are engaged when the outer housing is placed on the inner housing. To secure the two parts, a locking part 420, having a generally U-shaped cross-section, is slid over the two flanges 400, 410 so that the two flanges 400, 410 are clamped between two side arms 420a of the locking part 420. Again, when there is fluid pressure at the delivery port, this pushes the two flanges hard against the side arms 420a of the locking part 420, thus making it very difficult for a user to slide the locking part back off the flanges 400, 410. Moreover, as with the bayonet formation, a click fit arrangement may also be employed to further impede a user in removing the locking part 420 when the modulator is pressurised. In this case, the locking part may be provided with a protuberance which locates in a recess in one of the flanges, or one of the flanges may be provided with a protuberance which locates in a recess in one of the side arms 420a of the locking part 420.

Advantageously, two or more bayonet connector formation and bayonet receiving formations or two or more pairs of flanges and slide locks are provided.

It should be appreciated that the seals used in the modulator 111 need not be O-rings, and instead of having a generally circular cross-section, may be X or Z-shaped in cross-section, or may comprise a lip seal or any other suitable sealing means which allows relative movement of the two parts in question, whilst providing a seal between the two parts.

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

The invention claimed is:

1. A valve assembly comprising an inner housing in which is provided a first port, a second port, and a third port, there being located within the inner housing a valve member assembly which is movable between a first position in which the second port is connected to the third port whilst the first port is closed by the valve member assembly, a second position in which the first port is connected to the second port whilst the third port is closed by the valve member assembly, and a third position in which at least two of the first, second and third ports are closed by the valve member assembly, wherein the valve assembly further comprises an outer housing which is separate from and encloses at least part of the inner housing, the outer housing having a first port and a second port, the inner housing and outer housing each being provided with first mating parts, which engage to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the first port of the inner housing and the first port of the outer housing, and second mating parts, which engage to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a con-

duit for fluid communication between the second port of the inner housing and the second port of the outer housing.

2. A valve assembly according to claim **1** wherein the inner housing is provided with a fourth port flow which is connected to the valve member assembly such that the pressure of fluid at the fourth port controls movement of the valve member assembly between the first position, second position and the third position.

3. A valve assembly according to claim **2** wherein the outer housing is also provided with a third port and a third mating part which engage with the third mating part of the inner housing to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the fourth port of the inner housing and the third port of the outer housing.

4. A valve assembly according to claim **3** wherein the inner housing encloses a volume and the valve member assembly includes a movable element which divides the volume enclosed by the inner housing into a control chamber and a main chamber, the first, second and third ports extending into the main chamber, and the fourth port extending into the control chamber.

5. A valve assembly according to claim **3** wherein the first port and the fourth port are provided in the same side of the inner housing.

6. A valve assembly according to claim **5** wherein the fourth port in the inner housing comprises a generally annular aperture in the inner housing which surrounds and is substantially coaxial with the first port.

7. A valve assembly according to claim **4**, wherein the inner housing is provided with a fifth port which is connected to the control chamber, and the outer housing is also provided with a fourth port and a fourth mating part which engages with a fourth mating part of the inner housing to provide a substantially fluid tight seal between the inner housing and the outer housing whilst enclosing a conduit for fluid communication between the fifth port of the inner housing and the fourth port of the outer housing.

8. A valve assembly according to claim **7** wherein the first port, the fourth port and the fifth port are provided in the same side of the inner housing.

9. A valve assembly according to claim **1** wherein the outer housing is provided with a plurality of ports in fluid communication with the second port of the inner housing.

10. A valve assembly according to claim **4** wherein the valve assembly further includes at least one electrically operated valve which controls flow of fluid into and out of the control chamber.

11. A valve assembly according to claim **10** wherein the outer housing is formed in two parts, the ports being provided in a first part of the outer housing, and electrical control components by means of which operation of the at least one electrically operated valve may be effected being mounted on the second part.

12. A valve assembly according to claim **1** wherein the outer housing may include an aperture which is in fluid communication with the third port of the inner housing.

13. A valve assembly according to claim **12** wherein the outer housing supports a valve member which is adapted to restrict flow of fluid through the third port of the inner housing into the inner housing.

14. A valve assembly according to claim **1** wherein the inner housing is placed in the outer housing by translational movement in a first direction, and the inner housing is secured relative to the outer housing by a locking means which comprises a locking part which engages with the surface of one or both of the inner housing and outer housing to prevent separation of the inner housing and outer housing, release of the locking means to permit separation of the inner housing and outer housing being achieved by sliding the locking part along said surface in a second direction generally perpendicular to the said first direction.

15. A valve assembly according to claim **14** wherein the inner housing is secured relative to the outer housing by means of a bayonet connection.

16. A valve assembly according to claim **15** wherein the inner housing is provided with a male bayonet connector formation which is located in a corresponding recess provided in the outer housing.

17. A valve assembly according to claim **14** wherein the inner housing is secured relative to the outer housing by means of a slide lock.

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